Evaluating the Proposed Nuclear Power Renaissance[1]

by Howard Wilshire*

> You can't go very wrong with wind and solar power. You CAN go very wrong with nuclear power.
>
> Auntiegrav, posted on The Oil Drum, July 31, 2007

As the 70-year interval of cheap oil trickles to an end, it is becoming ever more evident that the economic edifice built on petroleum will crumble as depletion makes petroleum products more and more expensive.[2] Everybody has a stake in the energy mix this nation chooses to pursue. People around the globe are in the same boat, but most are ready to take on faith that some technology will solve the problem and allow all the world's economies to go on following the U.S. example: increasing energy consumption, and expanding development and consumerism.

Sorting useful information from misinformation is increasingly difficult, particularly in media presentation of claims fed to it by self-interested industries, which promise perpetual energy machines along with ways to bridge the transition from oil to whatever will replace petroleum with an "alternative" fossil fuel. Cleaning up dirty, but supposedly abundant, coal, is a favorite impossible dream.[3]

The competition for subsidy dollars is fierce, and greenwash is flowing freely. Not least is hype from the nuclear power industry, as it vigorously positions for a comeback.

The 1979 Three Mile Island (TMI) incident destroyed favorable notions of nuclear power plants in the U.S., but the nuclear power industry has convinced many journalists that the TMI accident was actually quite benign.[4] Reputable newspapers now suggest that the safety issues that led to TMI have diminished and reliability is improved, allowing the U.S. to embrace nuclear power. In a recent example, *The Christian Science Monitor* affirmed "US plants have logged nearly three decades of safe, uneventful operation."[5] Others have even cited improved oversight by the Nuclear Regulatory Commission (NRC).

But how good is the record really? The 30-year record of plant safety since TMI and the proposals being pushed to replace our aging fleet of inefficient reactors provide some unsettling clues.

Shoddy and Aging

Shoddy or incorrect construction has characterized many nuclear power plants and small accidents happen all the time. For example, part of California's Diablo Canyon nuclear plant ended up being built inverse to the blueprint design. None of the three Brown's Ferry, Alabama reactors matched their blueprints, and following the serious 1976 fire all were shut down in 1985 for reconstruction.

Nuclear power plant accidents may have helped improve other plants, but they resulted as much from human mistakes as from technical problems, a far more difficult issue to address, let alone solve. For example, during both the Three Mile Island and Brown's Ferry incidents, confusing instrument readings led to human errors that worsened the damage.

Reactors in the United States are aging and close to or past their design lifetime, raising the likelihood that new vulnerabilities will develop, exposing previously unknown design or construction flaws. Since the 1990s, and as recently as June 2009, radioactive tritium-water leaks have been discovered at more than a dozen elderly nuclear power plants.[6] New radioactive water leaks were found in the nation's oldest reactor just days after it was given a 20-year operating extension by the tolerant NRC.[7] In addition, the on-site storage of spent fuel rods in deteriorating facilities pose serious leakage problems.[8] Reports from various sites indicate tritium contamination in groundwater at levels much higher than the federal limit for drinking water.[9] Tritium pollution of drinking water carries serious risks to human health.[10]

The Christian Science Monitor praised the "admirable safety record" of the power plants and the New York Times cites marked improvement in their reliability. The facts do not support either claim, nor do they support the Monitor's assertion that safety improvement is "…in part due to the operators' willingness to cooperate closely with the NRC," which is supposed to protect the public by assuring responsible management and operation of nuclear power plants.

To the contrary, the 2002 discovery of a pineapple-sized corrosion hole in a pressurized reactor vessel at the Davis-Besse plant near Toledo, Ohio, raised alarms about another 68 reactors of similar design. Only a skin-thin stainless steel liner prevented the reactor from rupture, which could jam or destroy the control rod mechanism and leave operators powerless to stop a meltdown—the worst-case nuclear accident.

The record of Davis-Besse regulatory oversight shows that the NRC was cooperating with the operators to overlook problems. All were hidden from the public, and either were not reported to state and federal authorities as required by law, or were ignored by NRC regulators until someone blew the whistle.

There also is no shortage of recent nuclear reactor problems around the globe, ranging from operators' fumbling responses to natural geologic hazards such as earthquakes, and to accidents, obsolescence, and new reactor design flaws.[11] In addition, water supplies required for cooling most reactor designs are increasingly at risk with climate change. Closure or threatened closure of nuclear power plants in Europe and the U.S. has been caused by heat waves and drought for the past decade.[12]

Immediate Problem

Nuclear proponents see the immediate problem as a need to expand nuclear's present 20% of our electricity generation while avoiding the climate problems that would come from coal burning, now supplying about 47% of our electricity. The most significant environmental benefit ascribed to nuclear power is a reduction of greenhouse gas emissions compared to any use of coal. But supplying just today's energy demand will require many hundreds of power plants, enhancing the risk of serious accidents.

To accomplish the conversion from fossil-fuel fired to nuclear power plants, the industry has requested immediate subsidies, amounting to major infusions of federal dollars.[13] The money supposedly would be used for inventing technologies to improve the efficiency and safety of current and aging reactors, without adding to the world's burden of nuclear weapons proliferation. Not surprisingly, the industry does not explain how it expects to finally find a way to safely dispose of the dangerous wastes.

"New" Reactors: Integrated Fast Reactor

Even with heavy federal subsidies, adding to or replacing the 104 currently operating light-water reactors in the U.S. is proving economically difficult.[14] The two most commonly promoted replacements, which supposedly will lower costs, and address proliferation, waste disposal, and depletion of fuel supplies, are "sodium-cooled Integrated Fast Reactors" (IFRs) and thorium-fueled reactors.[15]

IFRs, also called "fast reactors" were initially designed to *produce* plutonium fuel for augmenting dwindling uranium supplies. In 1994, and again in 2003, concerns about nuclear weapons proliferation and excessive costs shelved two IFR designs. Now the industry is trying to rebrand IFRs as a means of *consuming* the plutonium and uranium in high-level radioactive power plant wastes, thus "solving" both proliferation and waste disposal problems.

In reality, an IFR's radioactive wastes pose the same disposal problems as the wastes it consumes.[16] To turn the wastes into IFR fuel requires reprocessing (see below), which itself yields bomb-usable materials. Reprocessing does not use up all the long-lived radioactive materials, and the problem of waste disposal remains unsolved. Coupling mutually dependent reprocessing and reactor facilities at the same site, as suggested by proponents, does not prevent use of the materials for bombs.

Past experience calls the safety of IFRs into question. For example, this assessment from Amory Lovins:

> IFRs might in principle offer some safety advantages over today's light-water reactors, but create different safety concerns, including the sodium coolant's chemical reactivity and radioactivity. Over the past half-century, the world's leading nuclear technologists have built about three dozen sodium-cooled fast reactors, 11 of them Naval. Of the 22 whose histories are mostly reported, over half had sodium leaks, four suffered fuel damage (including two partial meltdowns), several others had serious accidents, most were prematurely closed, and only six succeeded. Admiral Rickover canceled sodium-cooled propulsion for USS Seawolf in 1956 as "expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair." Little has changed. As Dr. Tom Cochran of NRDC notes, fast reactor programs were tried in the US, UK, France, Germany, Italy, Japan, the USSR, and the US and Soviet Navies. All failed. After a half-century and tens of billions of dollars, the world has one operational commercial-sized fast reactor (Russia's BN600) out of 438 commercial power reactors, and it's not fueled with plutonium.[17]

Robert Alvarez added:

> At least 15 "fast" reactors have been closed due to costs and accidents in the U.S., France, Germany, England, and Japan. There have been two fast reactor fuel meltdowns in the United States including a mishap near Detroit in the 1960's. Russia operates the remaining fast reactor, but it has experienced 15 serious fires in 23 years.[18]

Reprocessing Nuclear Wastes: Fuel for IFRs

During disassembly and chemical treatment of nuclear fuel rods, a reprocessing plant releases about 15 thousand times more radioactivity into the environment than nuclear reactors and generates dangerous waste. According to Alvarez,

> If placed in a crowded area, a few grams of [reprocessing] waste would deliver lethal radiation in a matter of seconds. [Reprocessing wastes] also pose enduring threats to the human environment for tens of thousands of years.[19]

People living near England's Sellafield reprocessing plant are exposed to radiation doses as much as 10 times higher than the general population receives. Releases of the extremely long-lived carcinogen iodine-129 have contaminated shores of Denmark and Norway at levels 1000 times higher than nuclear weapons fallout.[20] This spread of contaminants has led to protests from Denmark, Norway, and Ireland against British and French reprocessing plants.

Reprocessing of tens of thousands of tons of spent uranium fuel for plutonium production has created the United States' worst nuclear wasteland at the Hanford Reservation in Washington. Leaks from waste-filled tanks and other Hanford disposal facilities have contaminated huge volumes of soil and groundwater, leading to radioactive contamination in the Columbia River. As Alvarez notes, "the nation's experience with this mess should serve as a cautionary warning."

We are not very good at heeding such warnings, but if we choose to go ahead with recycling spent power plant reactor fuel we will generate a level of radioactive waste that dwarfs that of the nuclear weapons program, and generates about 25 times more radioactivity.[21] Assuming the industry's hoped-for renaissance comes to pass, the wastes will only get bigger and more unmanageable.

Thorium Fuel for Reactors

Recognizing the reprocessing problem, part of the nuclear industry is talking up thorium for power plant fuel. Three times as abundant as uranium, thorium can be used in various types of reactors, including Light Water, IFR, and others. Thorium proponents claim it can supply nuclear reactor fuel for hundreds of years, that it is "proliferation resistant," has relatively low cost, and will greatly reduce the hazard life of waste.[22]

Thorium is not fissile and cannot by itself serve as a fuel for nuclear reactors, however. Fissile isotopes, such as uranium-235 or plutonium-239, still must start and maintain the chain reaction until enough thorium has been converted to fissile uranium-233 to take over the chain reaction.[23]

Most proposed thorium fuel cycles also require reprocessing to separate uranium-233 for use as fresh fuel. Claims for this process as "proliferation resistant" are based on its dilution of uranium-233 by non-fissile (but radioactive) uranium-238. While additional uranium-238 does dilute the uranium-233, it also increases the stocks of fissionable plutonium-239.[24] With little further treatment all three fissile materials used in this process are suitable for making nuclear bombs, so pose the same opportunities for proliferating nuclear weapons as all nuclear reactors and reprocessing facilities.

Proponents of thorium fueled reactors claim that the wastes have a much shorter hazard life than those produced by other nuclear reactors—the same argument made for IFRs. But even though the mix of fission products in the waste differs from that of uranium fuel, it still contains dangerous long-lived radionuclides that must be isolated to protect life on Earth. It makes no difference whether the waste is reprocessed or not, it is still dangerous.

Experimentation with thorium fuel by Germany, India, Japan, Russia, the UK, and the U.S has met with continual technical difficulties for decades. A major difficulty is the uranium-232 created along with uranium-233. Uranium-232 has a half-life of about 70 years, but it is very radioactive and therefore dangerous in even very small quantities. It also gives rise to highly radioactive decay products, so that fuel fabrication with uranium-233 is very expensive and problematic.[25]

The Human Face

It's probably true that our 30 years of experience with current nuclear reactors has improved their safety.[26] but their future performance depends on how well they age with unknown inherited design and construction flaws.[27] The known operational challenges of currently proposed replacement reactors will not reduce our vulnerability, either. However, addressing the technical issues is no guarantee of safety, since all of the major nuclear reactor failures have been greatly enhanced by human failures, varying from human error to deliberate sabotage. Add to that the plain and simple carelessness that comes with cozy relationships between operators and overseers.

It is still not proved that training can overcome these human foibles. Because of the uncertainties industry refuses to function without the Price-Anderson Act guarantee that public money will pay for most of the cost of a Chernobyl-level disaster.[28]

High-level Elephant in the Low-Level Room

The rush to expand the U.S.'s nuclear power capability should be moderated by the unresolved problem of disposal for the high-level radioactive wastes generated by nuclear power reactors. This problem has not been solved anywhere in the world, and all such wastes now reside in vulnerable temporary disposal sites. Abandoning the multibillion dollar Yucca Mountain disposal site[29] leaves us with few and not very satisfactory options.[30] Compared to most other nations, the United States has a bigger, self-inflicted, problem of not defining high-level and low-level waste by the level of radioactivity and half-life. Instead, the U.S. includes some high-level wastes in the definition of low-level wastes, and so allows disposal of dangerous long-lived radioactive materials in leaking low-level waste sites.[31]

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Endnotes

1. Adapted from Howard G. Wilshire, Jane E. Nielson, and Richard W. Hazlett, *The American West at Risk: Science, Myths, and Politics of Land Abuse and Recovery*, Oxford University Press, 2008, pp. 328-334.

2. Research by the Association for the Study of Peak Oil and Gas (http://www.peakoil.net/), and related national organizations, has long since demonstrated that discovery of new cheap-oil deposits is far outstripped by consumption of this commodity. Cheap oil now is either in or very close to terminal decline. For information relevant to peak oil, gas, and other commodities, The Oil Drum (http://www.theoildrum.com/) and the Energy Bulletin (http://www.energybulletin.net/) are highly recommended.

3. U.S. Energy Secretary, Steven Chu, promised $2.4 billion for rapid development of technologies to reduce greenhouse gas emissions from coal (The Oil Drum, May 15, 2009). The abandoned FutureGen "clean coal" project in Mattoon, Illinois, is in process of resurrection with a provisional agreement in June 2009 for the DOE to kick in $1.1 billion in funding. Success in these matters will rapidly balloon prices of coal-generated electricity. The resource, much more limited than widely supposed, will follow the path of cheap oil. For additional information on coal reserves, see Energy Watch Group, Coal: Resources and Future Production, EWG-Paper No. 1/07; Richard Heinberg, Coal in the United States, *The Oil Drum*, May 29, 2008; Richard Heinberg, *Blackout: Coal, Climate, and the Last Energy Crisis* (Canada, New Society Publishers, 2009).

4. The Three Mile Island incident is seen by some to prove "…if nothing else, that the consequences of a nuclear accident were not as serious as imagined." After all, "no one was hurt" (William Tucker, Three Mile Island—Thirty Years Later, *The Infrastructurist*, April 2, 2009; see also, Alan W. Dowd, Commentary: Nuclear Power Is Clean Energy for a Post-carbon Era, *McClatchy Newspapers*, May 21, 2009). The actual health impacts of the accident are open to question because of design flaws in follow-up epidemiologic studies (S. Wing, D. Richardson, D. Armstrong, and D. Crawford-Brown, A Reevaluation of Cancer Incidence Near the Three Mile Island Nuclear Plant: The Collision of Evidence and Assumptions. *Environmental Health Perspectives* 105:52–57, 1997; Steve Wing and David Richardson, Collision of Evidence and Assumptions: TMI Déjà View, *Environmental Health Perspectives* 108 (12):A546-A547, 2000).

5. Monitor's Editorial Board, Nuclear Power Can Be A Safe, Clean, Major Source of Electricity, *The Christian Science Monitor*, October 21, 2008; Matthew L. Wald, Nuclear Power Revival Under Way in U.S., *The New York Times*, October 24, 2008. Another writer (Tucker, Three Mile Island—Thirty Years Later) concludes that while the Three Mile Island accident was caused by the "culture surrounding nuclear power, rather than the technology", "…the industry has learned its lesson and improved operating and safety procedures almost beyond recognition."

6. Supposedly regulated and monitored releases of tritium are routine at all U.S. nuclear power plants, but not necessarily harmless (Annie Makhijani and Arjun Makhijani, Radioactive Rivers and Rain: Routine Releases of Tritiated Water From Nuclear Power Plants. Science for Democratic Action 16 (1):1-10, 17 (2009). Inadvertent, unmonitored releases are reported from the Braidwood, Byron, and Dresden reactors in Illinois, the Palo Verde reactors in Arizona, the Indian Point nuclear plant near New York City, and a retired reactor at San Onofre in California. *Public Citizen*, Tritium Leaks at Nuclear Power Plants Contaminate Groundwater, http://www.citizen.org/, undated; Michel Lee, Defunct Reactor at San Onofre Now Found To Have Been Leaking for Duration Unknown, *San Diego Tribune*, August 17, 2006. In June, 2009, reports of 3.2 million piC/L tritium concentrations in a monitoring well, storm drains, and a concrete vault at the Dresden, Illinois plant were claimed to be no threat to public health (Sophia Tareen, Exelon: No Public Threat from Illinois Tritium Leak, Associated Press, June 8, 2009).

7. Wayne Parry, As the Nation's Oldest Nuclear Power Plant Shows Its Age, Some Call It Oyster Creak, Associated Press, September 9, 2009

8. Leakage of tritium and strontium-90 through cracks in a concrete containment wall around a spent fuel rod pool at the Indian Point plant may be contaminating the nearby Hudson River. *Public Citizen*, Tritium Leaks at Nuclear Power Plants Contaminate Groundwater, http://www.citizen.org/, undated

9. 20,000 pico Curies/liter (piC/L).

10. Tritium is a highly radioactive isotope of hydrogen, with a specific activity of almost 10,000 curies per gram. In gaseous form, it poses far fewer risks than in other chemical forms. Since tritium has the same chemical properties as hydrogen, it can combine with oxygen to form water. Such tritiated water is radioactive, and has become one of the problem pollutants at many nuclear facilities. In some places it has contaminated groundwater and surface water and continues to do so. Since plants, animals and humans process tritiated water in the same way as ordinary water, the tritium in it can be incorporated into chemicals, such as proteins, needed by the body. Thus, it can become part of human DNA. It can affect developing fetuses. Unfortunately, effects such as miscarriages in early pregnancy that may be induced by exposure of pregnant women to tritiated water are not well studied. Further, the combined effects of in-utero exposure to substances such as tritium, combined with endocrine disrupting chemicals such as dioxins or

PCBs, are also not well understood." Quoted from: Arjun Makhijani, Statement on Tritium, *Institute for Energy and Environmental Research*, February 6, 2006. A 2006 Nuclear Regulatory Commission report, based on inadvertent tritium leaks from three power plants, takes a much more benign view of the health risks. U.S. Nuclear Regulatory Commission, *Liquid Radioactive Release: Lessons Learned Task Force*, Final Report, September 1, 2006.

11. Wikipedia provides extensive, but not complete, lists of nuclear power plant accidents and accidents with nuclear materials at: http://en.wikipedia.org/wiki/List_of_civilian_nuclear_accidents. See also, Brad Knickerbocker, Accidents Dim Hopes for Green Nuclear Option, *Christian Science Monitor*, July 19, 2007; Geoffrey Lean, Safety Threat to Planned Nuclear Power Stations, *The Independent*, May 10, 2009; Sophie Borland, How a Trip to the Laundry Averted Nuclear Disaster, *MailOnline*, June 12, 2009; Robin Pagnamenta, UK Regulator Raises French Nuclear Concerns, *TimesOnline*, July 1, 2009

Automatic shutdowns of aging German plants led to a call for permanent closure (Brian Parkin and Lars Paulsson, German Minister Gabriel Seeks Earlier Reactor Closure, *Bloomberg*, July 6, 2009). Factors of concern in aging reactors include brittleness of steel exposed to radiation for long periods, and changes in modulus of elasticity in concrete with time, which in turn changes seismic response characteristics adding risk of system failures during earthquakes (Ernest Goitein, written communication 2009).

Following revelations of Japanese nuclear power plant inspection falsifications, a major earthquake in 2007 shut down Japan's largest reactor station amid misrepresentations of how the event was handled (Osamu Tsukimori, Japan nuclear power plant on long road to recovery, *Reuters*, 16 January 2008).

12. Robin Pagnamenta, France Imports UK Electricity As Plants Shut, *The Times*, July 3, 2009 reported that summer heat waves so far have forced several of France's inland nuclear power plants to shut down in 2009; Julio Godoy, Dangerous Summer for Nuclear Power Plants, *Inter Press Service News*, July 9, 2005. Keeping France's nuclear power plants running in 2003 required override of regulations governing temperature of water released from the plants. Other closures in Europe and the U.S. due to drought or heat waves occurred periodically back to 1999 (Jay Reeves, Hot Weather Forces Partial Shutdown of TVA Nuclear Plant, *Tennessean.com*, August 18, 2007; James Kanter, Global Warming Imperils Its Potential Solution, *International Herald Tribune*, May 21, 2007; Julio Godoy, Heat Wave Shows Limits of Nuclear Energy, *Inter Press Service News*, July 27, 2006; Colin Woodard, The Danube and Europe's Other Rivers Thirst for Water, *The Christian Science Monitor*, October 2, 2003; The Chronicle-Telegram, Hot Weather, Low Lake Threaten Nuclear Plants, *The Chronicle-Telegram*, August 10, 1999). The problem of limited cooling water availability from rivers and reservoirs is likely to worsen with climate change.

13. The Government Accountability Office, Federal Electricity Subsidies: Information on Research Funding, Tax Expenditures, and Other Activities That Support Electricity Production, GAO-08-102 (2008) estimated that nuclear programs received the largest share of electricity-related R&D funding from FY 2002 through FY 2007, amounting to $6.2 billion, or 54% of such subsidies. This directly contradicts the claims of the Nuclear Energy Institute, Federal Subsidies Not High, Comparatively Speaking, Nuclear Energy Institute, November/December, 2008. The DOE is putting up $18.5 billion in loan guarantees for construction of new nuclear power plants, with more likely to come (Steven Mufson, Government to Guarantee Loans for Nuclear Power Plants, Washington Post, June 17, 2009). The numerous pitfalls of ramping up nuclear power plants, and putting off to the distant future the problems of cleaning up decommissioned facilities, is amply illustrated by weapons site cleanup issues (Kimberly Kindy, Nuclear Cleanup Awards Questioned: Firms Cited for Errors Get Funding, Washington Post, May 18, 2009).

14. New commercial nuclear power plants cost billions of dollars to build—a $6 billion price tag shelved a planned facility in Missouri in April 2009. Building new light water reactors is even less likely because of their inefficiencies and cost.

15, Amory B. Lovins, "New" Nuclear Reactors, Same Old Story, *Rocky Mountain Institute*, 2009. This paper provides a good summary of IFR and thorium-fueled reactor issues.

16. The mix of radioactive elements is broadly similar in any nuclear fuel cycle. IFR wastes may contain lower concentrations of transuranic elements, but include very long lived isotopes such as iodine-129 (half life 15.7 million years), a carcinogen, and technetium-99 (half life 212,000 years) (Lovins, "New" Nuclear Reactors, Same Old Story).

17. Lovins, "New" Nuclear Reactors

18. Robert Alvarez, *Nuclear Recycling Fails the Test* (Washington, DC: Foreign Policy In Focus, July 7, 2008). This report is an extremely valuable, thorough assessment of claims for safe, economical, and non-proliferation-inducing reprocessing of nuclear wastes, and history of fast reactors. According to Lovins, commonly cited alternatives to chemical processing, for example high-temperature pyrometallurgy and electrorefining, present different but still major challenges, greater technical risks and repair problems, and speculative but probably worse economics ("New" Nuclear Reactors, Same Old Story). In addition to the reactor failures cited by Lovins and Alvarez, the Department of Energy dismantled its Fast Flux Test Facility, a 400-megawatt sodium-cooled fast neutron flux test reactor in 2002.

19. Alvarez, Nuclear Recycling.

20. Alvarez, Nuclear Recycling.

21. Avarez, Nuclear Recycling.

22. Arjun Makhijani and Michele Boyd, Thorium Fuel: No Panacea for Nuclear Power. *Physicians for Social Responsibility and the Institute for Energy and Environmental Research*, Fact Sheet, April 2009. This is an authoritative assessment of thorium fuel. See also, Lovins, "New" Nuclear Reactors, Same Old Story.

23. Plutonium-239 is produced by neutron bombardment of uranium-238 in reactors.

24. Makhijani and Boyd, Thorium Fuel.

25. Makhijani and Boyd, Thorium Fuel.

26. Martin Sevior, Is Nuclear Power a Viable Option for Our Energy Needs? *The Oil Drum*, August 8, 2006; see also http://nuclearinfo.net.

27. James Rosen, Inspectors Find Safety Problems At Nuclear Weapons Complex, *McClatchy Newspapers*, May 2, 2009 cites a recently completed DOE Inspector General's finding that contractors at the Savannah River nuclear weapons facility repeatedly used substandard construction materials and components, risking a major accident. Standards for construction of nuclear facilities, private power plants included, appear lacking.

28. The Price-Anderson Act caps the nuclear power industry's liability for a serious accident at $10 billion. Taxpayers get stuck with the balance of the anticipated $500 billion in damages.

29. President Obama announced in February 2009 that the multibillion dollar Yucca Mountain high-level radioactive waste site is to be replaced.

30. Options for high-level waste disposal are: indefinite storage in 35 states and 75 reactor sites, 10 of which have been decommissioned; consolidation of wastes at a central location, which would not provide permanent storage; restart the process of locating and developing geologic repositories, knowing that Yucca Mountain took 3 decades and many billions of dollars (Rodney C. Ewing and Frank N. von Hippel, Nuclear Waste Management in the United States—Starting Over, *Science* 325:151-152 (10 July 2009).

31. Wilshire et al., The American West at Risk, p. 276-279. Plutonium disposal at low-level sites include 450 pounds at Richland, Washington, 140 pounds at Maxey Flat, Kentucky, and 47 pounds at Beatty, Nevada.