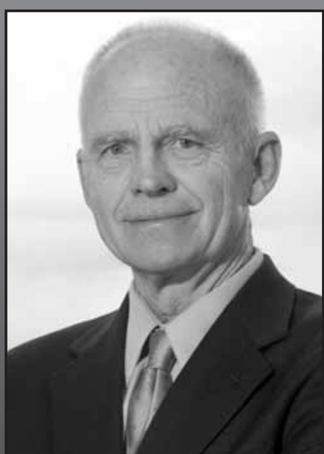
PERSPECTIVE

THE PARADOX OF NUCLEAR WASTE

Understanding Nuclear Waste and Its Role in the Coming Nuclear Expansion

By Harold F. McFarlane



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One's Man's Waste Is Another Man's Treasure

I was at a bar on the beach where a bunch of happy people were celebrating when the idea for this perspective came to me. On January 19, 2006, I had the privilege of watching the launch of an Atlas V rocket from the Kennedy Space Center. Zipping by the moon in only nine hours, it was the fastest object ever created by humans.

The launch was the culmination of 17 years of effort by a dedicated team of scientists and engineers. In another nine years they'll be able to flip a switch and begin humankind's first close encounter with the planet Pluto. Once the rocket parts had fallen away, all that was left was the Pluto/New Horizons Observatory coasting along at 27 000 miles per hour. This is the National Air and Space Administration's (NASA's) most important science mission of the decade.

The NASA science team is confident that when they flip that switch to start recording and transmitting data, more than 200 watts of electricity will be available out there in the coldest and darkest region of the solar system, some 40 astronomical units from home. The power is provided by a radioisotope thermoelectric generator, a space technology that NASA has successfully used for four decades on some 25 missions.

That brings me to why I was there. Our team at the Idaho National Laboratory had fueled the generator with plutonium-238, delivered it to the Cape, and watched over it until the launch. Having not done any of the actual work, I was there to help out with the celebration.

It was during the party that one of the Lockheed engineers, flushed with pride and relief that his rocket had performed as advertised, gave me the first half of the idea. He said, "You guys just sent 24 pounds of plutonium on its way out of the solar system. That is the ultimate nuclear waste disposal." But within 10 minutes, the U.S. Department of Energy program manager looked me in the eye and said, "Damn, that's 24 pounds of plutonium that I have to replace."

Having just read Alan Waltar's wonderful new book, *Radiation and Modern Life,* I was reminded that one man's waste is another man's treasure. Herein, I want to explore some of those contradictions.

Waste versus Treasure

Most of us in the nuclear industry think about radioactive waste as ordinary stuff contaminated with activation products or fission products from nuclear operations. Fission products include most of the elements in the periodic table—everything between zinc and holmium, plus tritium and the transuranics, and of course all the radioactive decay daughters. In that context, just about every element we know of can become a part of a radioactive waste stream.

However, if we consider the medical, agricultural, industrial, and other applications, about two-thirds of the elements in the periodic table include radioisotopes that have beneficial uses.

Most people are aware of some of the medical applications, ranging from diagnostic tests to treating aggressive cancers. Perhaps half of all patients who enter modern U.S. hospitals are touched in some way by radiation technology, whether by diagnosis, treatment, or equipment sterilization.

Most of the prioritized science missions for future solar system exploration will be made possible by radioisotope power systems, which will allow space missions to venture to the moons of Jupiter and to the sun, where powerful magnetic fields have trapped high-energy ionized particles that would destroy solar panels.

The irony is that the medical industry has gradually dropped the word nuclear from its vocabulary even as its practitioners take advantage of nuclear's benefits. Now we have "magnetic resonance imaging" instead of "nuclear magnetic resonance," and the term "medical physics" encompasses a broad range of radiation technologies.

Modern industry, too, routinely uses radiation technologies for a variety of applications. Process control for thickness, density, and level typically employs nondestructive nuclear techniques. Radioisotopes are used in plant diagnostics. Gamma radiation is routinely used in polymer development for products such as heat-shrink fabrics. The rubber in tires is often vulcanized by radiation rather than chemical processes because the chemicals generate waste.

Radiation technology has long been used in agriculture. Among the best-known applications is pest control, which has successfully been used to remove infestations of Mediterranean fruit flies, screw worms, and gypsy moths. Worldwide, more than 2000 crop varieties have been developed through radiation-accelerated mutations and testing. Food safety through irradiation is becoming more accepted and has the potential for becoming a very large industry.

In the realm of public safety and crime fighting, nuclear technology has found many applications. The use of radioisotopes in smoke detectors, exit signs, and airport runway lighting has saved countless lives. Nuclear techniques have proven to be powerful forensic tools for fighting crime. And of course, we are all aware of the increasing role of high-sensitivity sensors and diagnostics in fighting terrorism.

Our ambivalence about nuclear materials is reflected in the way that we talk about nuclear fuel that has experienced life in a reactor. For a long period, high-level waste and spent nuclear fuel were synonymous. Recently, however, the country has started to acknowledge the 95 percent residual energy in this fuel that is far from spent. The term du jour is "used fuel." And in another decade or two, "feed material" may become a common name for spent fuel, as we move away from an extractive industry to a greener recycle nuclear economy.

Let me use one more Pu-238 illustration. The Government Accountability Office has estimated the cost of Pu-238 production to be about $5000 per gram. In the simplest case, it takes $1000 to initiate the shipment of waste contaminated with 1 g of Pu-238 to the Waste Isolation Pilot Plant in New Mexico. But in 2003, NASA loaded up a couple $300 million rockets with the solar-powered Mars rovers, *Spirit* and *Opportunity.* One of the nation's best-kept secrets is that each of those rovers contains eight little Pu-238 heaters to keep the axles and instruments warm through the Martian night—which I am told is colder than Idaho in February. Each of these heaters contains about 2 g of plutonium oxide, which supplies about 1 watt of thermal power.

As successful as *Spirit* and *Opportunity* have been, they've moved only a few hundred yards from where they landed. And they can operate only in the summer, during the daytime, and within 15 degrees of the Martian equator.

In 2009, NASA expects to launch a radioisotope-powered rover that can operate in more interesting regions of the planet, drill samples, and explore vast distances. Most of the prioritized science missions for future solar system exploration will be made possible by radioisotope power systems, which will allow space missions to venture to the moons of Jupiter and to the sun, where powerful magnetic fields have trapped high-energy ionized particles that would destroy solar panels. Radioisotope power will facilitate exploration on Venus's surface, where the temperature exceeds 400°C and dense clouds block the sunlight. And if the president's vision for human exploration is realized, even larger nuclear power systems will be required to keep those fragile astronauts alive and breathing.

Before getting back to terrestrial waste disposal, let's consider the economic benefits of radioisotope applications. The last survey of the economic impact of radiation technologies in the United States that I know about was in 1995. International Atomic Energy Agency data and a much more recent Japanese survey showed the same trends.

- In 1995 combined radiation technology industries had a larger sales volume than any single Fortune 500 company.
- The nuclear electricity component was less than 20 percent.
- As an industry, radiation technologies ranked just behind banking and ahead of electronics.
- The economic impact of the industry was slightly larger than either the Mexican or South Korean economies.

In more than a decade since that compilation was made, a lot has changed including increased use of radiation technologies, 7 million metric tons of CO_2 emissions avoided by the use of nuclear power, and a 20 percent increase in nuclear electricity production without construction of a single new plant.

In spite of all these benefits, responsible management of radioactive waste is challenged at every step and not just by activist groups. It has taken great tenacity by those involved in the waste industry to continue to make progress on keeping waste solutions open. It is neither easy nor pleasant to stand up to criticism and political pressure, but it is necessary for the future of our country.

Since 1980, the nuclear waste industry has reduced low-level waste volumes by more than 90 percent. Modern nuclear fuel yields more than twice as much energy as 1970s-vintage fuel, resulting in lower waste volumes. In New Mexico, the world's first deep geologic repository has now operated successfully for several years.

High-level waste is a perfect example of one of the contradictions that contributes to my paradox theme. When people hear that there are 44 000 tons of spent fuel looking for a permanent home, they have an image in their head of this mountain made up of highly sinister material. In fact, removed from its protective casks, all the spent fuel generated to date would fit on a football field with 20 yards to spare. One football field.

Another impetus for the resurgence of nuclear energy in the United States is the need to maintain some leadership and influence over the expansion of nuclear energy worldwide.

New Plants Ahead

The Energy Policy Act of 2005, better known as EPACT2005, contained provisions to stimulate new nuclear plant construction. The response of the nuclear industry and the financial markets has been positive. Most officials are now saying that we will have new nuclear plants on line by 2015. By 2020 new plant orders at the rate of two to three per year not only seems feasible, but likely.

In February, the administration announced a new initiative called the Global Nuclear Energy Partnership, or GNEP. Although it will take decades to fully implement, this initiative is a vision of an end state in which nuclear technology is a cornerstone of U.S. energy and nonproliferation policy.

These bold federal actions could initiate nuclear expansion that will extend throughout this century. Such an expansion is needed if nuclear is to hold or increase its 20 percent share of electricity generation and be used for new industrial applications such as hydrogen generation.

This growth coupled with the expansion in radiation technology applications means the expected growth in the power industry will challenge the waste industry. GNEP will bring with it the sanity of a closed fuel cycle and the power of reprocessing to waste management.

If anyone doubts that the United States will find the resolve for a national resurgence of nuclear energy, consider the pressure from abroad.

In the past two years, we have seen a jump in commodity prices, particularly for steel and concrete, driven by the building boom that is an expression of China's rapid economic expansion. India, the second most populous nation, is expanding just as rapidly and has perhaps an even stronger technology base. Both countries are acutely aware of the pressure that realizing the rising expectations of their burgeoning populations will place on the global energy markets.

About a year ago, my friends looked at me tolerantly when I told them that within three years we would see $3/gal gasoline and $75/barrel oil. With last season's hurricanes, it turns out that I was too optimistic about how long it would be before we saw record gas prices. Oil prices are volatile and have broken through the $75 mark and continue to dance between $70 and $80 per barrel. Similarly, this summer regular unleaded gasoline was running around $3 a gallon.

In spite of the rosy outlook of some economists who predict a return to $30/barrel oil, the truth is that global pressure on oil will see only an increase. Most of our supply comes from a politically unstable triangle in the Middle East that is no larger than the state of Arizona. New oil field discoveries are smaller, more expensive to extract from, deplete more quickly, and produce heavier oil that requires additional refining.

The rapid rise in natural gas prices caught many developers unaware, leaving a number of new gas turbine projects underwater even before their completion. Efforts to significantly increase gas supply through liquefied natural gas imports are largely being thwarted by community opposition.

There are large reserves of fossil energy in North America. With reserves measured in centuries, coal already supplies the lion's share of our electricity but needs improved technology to reduce its environmental impact. U.S. oil shale has the potential to yield up to 2 trillion barrels of oil equivalent under favorable economic conditions. The oil sands of Canada are huge fossil fuel reserves but are expensive to extract from and convert to useful petroleum products.

Most of these indigenous reserves will require vast quantities of hydrogen to convert them to gasoline, jet fuel, and diesel products. If nuclear is to supply that hydrogen—and control of greenhouse gas emissions seems to be pushing in that direction—rapid nuclear expansion will be required throughout the 21st century.

Another impetus for the resurgence of nuclear energy in the United States is the need to maintain some leadership and influence over the expansion of nuclear energy worldwide. Returning again to the example of southeastern Asia, both China and India plan to have more than 250 GWe of nuclear plants installed by midcentury, or together more than the world's currently installed nuclear capacity. Even so, nuclear will remain less than 10 percent of their total electrical generation.

India and China's plans are more ambitious than even our recent GNEP proposal. Both countries are proceeding at full speed to closed fuel cycles; both are constructing breeder reactors and expect them to be the dominant technology by midcentury. While we fret about perhaps building fast burner reactors to manage actinide waste, the developing countries realize that uranium resources will also be stressed like other commodities. They are planning ahead to reduce the global impact of their anticipated appetite for energy resources, including uranium.

Japan will continue its deliberate push toward a self-sufficient nuclear economy, although with less urgency due to a shrinking population and a mature economy. South Korea plans to continue rapid nuclear growth in both capacity and technology, mirroring the development ambitions of China, albeit at reduced scale. France has returned to fast reactor development after a 15-year hiatus, and Russia remains focused on advanced technologies.

By some counts, 123 new nuclear plants are planned or under construction worldwide; the much heralded nuclear renaissance is happening. It is just a matter of whether the United States will contribute or slip into the shadows.

I believe that the United States has only a brief window of opportunity to reestablish its international nuclear energy leadership. Such a move would be welcomed abroad, but other nations will not wait another decade for us to get over our hand-wringing episode. It is essential that we seize this opportunity to influence the international safety and nonproliferation regime to our standards. It is also important from an economic perspective to maintain at least parts of this key, high-tech industry in the United States—particularly after the loss of so many manufacturing jobs has discouraged many American workers.

For a Nuclear Resurgence

There are a number of conditions that must be satisfied if we are to have a true nuclear resurgence in this country:

- The first condition is reestablishing trust. We have come a long way with the public, with 70 percent now favoring new plant construction. However, there are still major issues at the state level. The recent episode with the questions regarding the integrity of the Yucca Mountain analysis shows just how expensive the loss of public confidence can be.
- A major reason for the lack of trust in the state governments is waste. The legacy of Cold War waste is still generating mistrust. The waste issues have to be resolved, solved, and streamlined if we are to move aggressively ahead on a civilian program.
- A third condition is resolution of the federal and private domains. Failure by the government to take control of the spent nuclear fuel in 1998 has generated bad consequences for both sides. As we move into materials recycling, the federal/private boundary for materials and facilities ownership must be resolved satisfactorily. Successfully closing this deal will require an unfamiliar level of leadership.
- The administration has been careful to cast its new initiative within a nonproliferation framework. The argument about whether we influence by leadership or by self-denial has to be resolved. The latter approach, first

expounded by President Carter, has been a consistently demonstrated failure. It is time for something new, and for this President Bush deserves high marks.

- Whatever our program, it needs to be sustainable through administration changes. There are broad elements that should be unassailable, and we need to learn to speak with one voice on those. In open forums we can argue about the rest.

To take just one of those conditions, for 20 years we have been trying to deal with the Cold War's legacy—a problem that is concentrated in a few states: primarily Washington, South Carolina, Idaho, Tennessee, Ohio, and New Mexico. Colorado has largely resolved its problems, no doubt in part because Rocky Flats exported its worst waste legacy to my state of Idaho.

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The bill for cleanup of the weapons complex will run into the hundreds of billions of dollars, even then with continued arguments and lawsuits about the definition of completion. This legacy continues to provide ample ammunition to those who oppose nuclear energy. More importantly, it puts key state governments in the unenviable position of trading off new nuclear development against progress on legacy remediation.

There will never be enough money in the federal budget to effect cleanup to a level that satisfies the very last person. The ultimate resolution will take creativity, statesmanship, and, most of all, tenacity. It won't be easy, and it won't be quick. The key for all of us is to recognize its importance to our nuclear future and keep on keeping on, as the saying goes.

While at times it seems that we are moving at a glacial pace on dealing with the Cold War legacy, there is at least one statistic that I find remarkably reassuring. On average, 1 out every 10 light bulbs in the United States today is powered by uranium downblended from former Soviet Union nuclear warheads that were once targeted at U.S. cities. That's real progress, even if there is a long way to go.

There are other positive signs of progress. Accelerated cleanup contracts are now setting the trend. At sites such as Idaho and Savannah River, where there are simultaneous cleanup and development activities, separate contracts are being written by the DOE to be sure that each set of activities can be independently prioritized.

Another essential item for a nuclear resurgence is the continued safe operation of existing nuclear power plants. The U.S. civilian nuclear industry has been one of the safest places to work. No death has been attributed to the nuclear side of the business, a remarkable statistic for such a large undertaking.

Chernobyl notwithstanding, the worldwide safety record with disposal of radioactive sources has not been as good as the power production side. There have been severe injuries and even deaths due to loss of control of industrial sources and radioactive scrap. Safety in cleanup and waste management activities will be just as important as power plant safety in maintaining public confidence in the years ahead.

With all the recent Utah-based activities, there is evidence of a maturing of the waste industry, with mergers, acquisitions, and now the U.S. Nuclear Regulatory Commission licensing of the Goshute temporary spent fuel storage facility. Industrial improvements tend to come naturally with the maturing process, because they simply make good economic sense.

One of my favorite examples is from the reprocessing industry in Europe. During the last 30 years, peak doses from reprocessing discharges at Sellafield have been reduced by a factor of 20. During the same period, liquid radioactive discharges at La Hague have been reduced by two orders of magnitude, worker exposures have been reduced by a factor of 20, and the average dose to the public is now less than 0.01 millisievert per year.

The American Nuclear Society's Role

Conferences such as the Tucson Waste Management meetings and the suite of conferences run by the American Nuclear Society (ANS) on fuel-cycle issues play an important role in technology exchange and in objectively defining the state of the industry. They provide an opportunity for peers around the world to get to know each other, to collaborate, to argue, and to form lasting bonds. They provide a forum for service providers and customers to hook up.

For those of you who are committed to a future in the nuclear business, I encourage you to join a professional association if you have not already done so. If you employ such folks, I encourage you to support their activities and to involve your company. At the ANS, we are just beginning to implement the latest revision of our strategic plan. Among other benefits of this plan, we will arm our 10 000-plus members with the tools they need to engage effectively in the upcoming public debates over nuclear expansion. It is important that we are all out there spreading the word about the benefits of our industry and putting its risks in proper perspective. ■

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