NUCLEAR MONITOR

A PUBLICATION OF WORLD INFORMATION SERVICE ON ENERGY (WISE)
AND THE NUCLEAR INFORMATION & RESOURCE SERVICE (NIRS)

wise
World Information Service on Energy
founded in 1978

NUCLEAR INFORMATION & RESOURCE SERVICE
www.nirs.org

MARCH 17, 2006 | No. 643

MONITORED THIS ISSUE:

RADIOACTIVE WRECK: The Unfolding Disasters Of U.S. Irradiated Nuclear Fuel Policies 1

RADIOACTIVE WRECK: The Unfolding Disasters Of U.S. Irradiated Nuclear Fuel Policies

***"Electricity is but the fleeting byproduct from nuclear power. The actual product is forever deadly radioactive waste."* --- Michael Keegan, Coalition for a Nuclear-Free Great Lakes**

The U.S. faces a deepening dilemma about what to do with its mounting high-level radioactive wastes. Whether in the core of an operating nuclear reactor; stored underwater in indoor pools or "dry" outdoor silos; transported by truck, train, or barge; chemically dissolved and "recycled"; parked on Indian reservations; or buried in earthquake zones, irradiated nuclear fuel is dangerous and deadly. None of the current proposals for already-existing atomic wastes can be considered "safe." The various alternatives merely amount to greater or lesser degrees of danger, to choosing between greater and lesser evils. A scientifically sound and socially just search for stable geology that could isolate radioactive wastes for the duration of their hazard has yet to be undertaken.

There are risks with keeping wastes where they currently are - largely at the nuclear power plants that generated them - as well as with moving them to "away-from-reactor" locations. For example, rising sea levels due to global warming could someday threaten wastes stored at reactors on the coastlines. Wastes stored at reactors in river flood plains, on eroding shorelines of lakes, or above aquifers threaten the contamination of surface and sub-surface waters if allowed to deteriorate and leak over time. Whether it is years, decades, or centuries before such risks become realities depends on local climatic and hydrologic circumstances.

Although, 75 percent of reactors are located east of the Mississippi River in the relatively populous East, many proposals for national waste dumps have targeted sparsely populated areas in the West. However, the long sought after Yucca Mountain (Nevada) dumpsite has fatally flawed geology, as well as the fastest growing city in the U.S. - Las Vegas - just 90 miles away, and sprawling ever closer as time goes by. The targeting of rural and minority groups with wastes generated by urban and majority populations raises significant moral and ethical questions but ironically, there are sites with more promising geology for the long-term containment of radioactive wastes in the politically powerful and populous East than in the West.

The goal of U.S. high-level radioactive waste policy must be to isolate the radiation for the duration of its hazard, to prevent environmental contamination, health and genetic damage, and the re-use of the wastes for weapons purposes. The only real answer to the nuclear waste problem is not to make anymore in order to prevent the doubling or tripling the size of the dilemma we already face.

What is High-Level Radioactive Waste?

The nuclear establishment in industry and government euphemistically refers to high-level radioactive waste as "spent" or "used" nuclear fuel. Irradiated nuclear fuel discharged from atomic reactors is highly radioactive, a million times more so than when first loaded into a reactor core as "fresh" fuel. This is due to the build up of fission products and transuranic elements during uranium atom splitting. If unshielded, irradiated fuel recently removed from a reactor could deliver a lethal dose of beta, gamma, and neutron radiation to a person standing close enough in seconds. Even after decades of radioactive decay, a few minutes of unshielded exposure would be enough to deliver a fatal dose. The vast quantities of radiation contained in concentrated stockpiles of irradiated fuel, if expelled into the environment by accident or on purpose, could kill or injure tens or even hundreds of thousands of people - or millions over time - and contaminate entire regions, causing hundreds of billions of dollars worth of damage.

Certain radioactive elements (such as alpha emitters, the most well known of which is plutonium-239) in "spent" fuel will remain hazardous to humans and other living beings for hundreds of thousands to millions of years. Thus, even if buried underground in leaky geology, these wastes could eventually escape back out into the biosphere, with disastrous consequences.

Reprocessed high-level radioactive wastes (HLRW) - the highly radioactive liquid, sludge, or re-solidified "leftovers" from physically chopping up and then chemically dissolving irradiated fuel in order to extract still-fissile plutonium and uranium - have most of the same hazardous characteristics as un-reprocessed irradiated fuel. Irradiated fuel and high-level nuclear wastes are among the most hazardous poisons ever created. In addition, there is the danger that fissile materials still present in the wastes can form a "critical mass," causing an inadvertent nuclear chain reaction that would generate a deadly beam of neutrons and possibly even enough heat to melt through the container within which it is held, worsening danger and hastening leakage. Thus, these wastes must be shielded for centuries, prevented from going critical for millennia, and isolated from the living environment virtually forevermore into the future.

How Much Radioactivity Is Where?

Nuclear fuel undergoing fissioning represents the most radioactive stage in the nuclear fuel chain. Due to a large number of radioactive isotopes with short lasting but acute hazards, a typical commercial reactor contains around 15 billion curies of radioactivity during operations. The bad news is that if just a fraction of that radiation escapes into the environment, it can cause widespread catastrophe. The Chernobyl nuclear power plant explosion and fire in 1986 involved an operating reactor and the resulting devastation impacted not only Ukraine, Belarus, and Russia, but also sent radioactive fallout across Europe and around the Northern Hemisphere.

The good news is, just one month after shut down, a reactor core's curie count decreases by 50 percent. How many environmental hazards or national security threats can be cut in half in just one month's time? (1) Given reactor locations - behind thick reinforced concrete containment shells in many cases - it would be challenging, but not impossible, for a direct attack on the reactor core to succeed. However, indirect attacks on a nuclear power plant's "soft spots" (control rooms, for example, are often outside containment and electricity supply to vital safety systems are both very vulnerable) could directly lead to a meltdown and catastrophic radiation release. As David Lochbaum at Union of Concerned Scientists has stated, "kill the brain, and the body is soon to follow." (2)

On-site storage pools contain most of the accumulated irradiated fuel ever generated at the reactor. Even after decades of thermal cooling and radioactive decay, individual pools still hold tens to hundreds of millions of curies. Thus, disastrous radiation releases could erupt from a pool that has lost its cooling water due to accidental boiling or drain down, or a deliberate terrorist attack. (3)

Outdoor dry storage casks, often vertical concrete and/or metal cylinders about 20 feet tall and 10 feet in diameter, are used at a growing number of nuclear power plants to hold the oldest wastes from pools with overfilling capacity. Each cask can hold, on average, hundreds of thousands to millions of curies. (4) Gigantic rail, barge, and heavy haul truck transport casks, weighing well over 100 tons, are of similar or identical size and radioactivity content to storage-only casks; they contain well over 200 times the long-lasting radioactivity released by the Hiroshima atomic bomb. Smaller truck casks for highway use each contain 40 times the radiation released at Hiroshima. (5)

Currently proposed centralized "interim" storage, permanent burial, and/or reprocessing facilities would concentrate large quantities of irradiated fuel from the 103 still-operating reactors and the 28 that have been permanently shut-down, as well as any that might be built in the future. The proposed Private Fuel Storage, LLC "interim" storage site for commercial irradiated fuel would park 40,000 metric tons - about 75 percent of the current nationwide stockpile - on an open air surface facility at the Skull Valley Goshutes Indian Reservation 45 miles upwind from Salt Lake City, Utah. The proposed permanent repository at Yucca Mountain, Nevada would hold 63,000 metric tons of commercial irradiated fuel (100 percent of the total projected to exist in the U.S. in 2010, but far less than would be produced should every reactor operate for its entire licensed term, and even less if reactors receive and operate for 20-year license extensions), plus an additional 7,000 metric tons of U.S. Department of Energy irradiated fuel and HLRW from the nuclear weapons complex, Navy nuclear fuel, U.S. research reactors, returned foreign research reactor fuel, etc. A national commercial waste-reprocessing center, as recently proposed after a 30 year halt on commercial reprocessing in the U.S., would likewise concentrate large quantities of irradiated fuel and HLRW in one location.

Dangers of Pool Storage

Storage pools located indoors at operating and permanently shutdown commercial nuclear reactors in the U.S. hold most of the irradiated fuel ever generated at those reactors. Thus, decades worth of waste, representing multiple full reactor core inventories, are stored in pools. (6) In fact, the pools at some reactors are crammed so full of waste that the density of nuclear fuel approaches that of operating reactor cores. (7) Boron dissolved in the storage pool water and boron impregnated metal sleeves placed between adjacent nuclear fuel assemblies are all that prevents inadvertent nuclear chain reactions in the pools due to the still-fissile contents of neighboring irradiated fuel assemblies! The vast majority of irradiated fuel generated over the past 50 years at commercial reactors is still stored in on-site pools. For reactors lacking dry cask storage, the pool often contains all the irradiated fuel ever generated there.

But "wet" storage underwater presents significant hazards. Water must continually cover irradiated fuel to provide both radiation shielding and thermal cooling. Water of sufficient depth must cover the waste to limit the radiation doses received by nuclear workers near the pools, and pumps must continually circulate the water to keep the thermally hot wastes cool. These operations must continue 24 hours a day, 7 days a week, for decades on end. Loss of the cooling water, or loss of circulating pumps such as by electricity outage, starts a ticking clock that could end in catastrophe. Both accidents and intentional attacks threaten these pools packed full of deadly atomic wastes. Examples of significant accidents in pools include inadvertent drain downs, such as at the Dresden nuclear power station in Illinois, and accidental dangles of heavy loads (namely, fully loaded radioactive waste dry casks, weighing tens of tons) for many hours or even days on end at such reactors as Prairie Island, Minnesota and Palisades, Michigan. (8) Depending on the configuration of the pool and its surroundings, the accidental drop of a heavy load could damage vital safety equipment for the pool, the operating reactor or even the pool itself, causing a loss of cooling water or the irradiated fuel located underneath (or in the dry cask itself).

In February 2001 the U.S. Nuclear Regulatory Commission (NRC) reported that the irradiated fuel in a drained pool could spontaneously combust. Without cooling water, the irradiated fuel could overheat so badly that the zirconium metal cladding on the nuclear fuel rods could catch fire. The fire could spread throughout the densely packed pool, engulfing decade's worth of accumulated high-level waste. The resulting atomic inferno would release catastrophic amounts of radioactivity in the escaping smoke, killing over 25,000 people as far as 500 miles downwind due to lethal acute doses and radiation-induced latent cancer fatalities. (9) Such deadly large-scale releases are all too possible given the fact that most pools, rather than being enclosed in radiation containment buildings, are merely housed in typical industrial warehouse-type buildings. Thus, there is little to prevent massive amounts of radiation from escaping into the environment.

Certain General Electric-designed "boiling water reactors" have elevated pools that share exterior walls with the outside of the nuclear power plant building, with little more than a thin metallic roof overhead. Such reactors - some located near major cities - are particularly vulnerable to terrorist attack. Despite a National Academies of Science report and the concerted efforts of concerned citizens and environmental groups, neither the NRC nor the nuclear power industry itself have taken any visible action to address such potentially catastrophic national security vulnerabilities. (10) Densely packed irradiated nuclear fuel storage pools represent massive "dirty bombs" vulnerable to detonation by well-organized, determined attackers.

Alvarez et al. sum up the potential consequences, "A 1997 study done for the NRC estimated the median consequences of a spent-fuel fire at a pressurized water reactor that released 8 to 80 mega-curies of cesium-137. The consequences included 54,000-143,000 extra cancer deaths, 2,000-7,000 square kilometers of agricultural land condemned, and economic costs due to evacuation of US$117-566 billion. It is obvious that all practical measures must be taken to prevent the occurrence of such an event." In short, "The long-term land-contamination consequences of such an event could be significantly worse than those from Chernobyl." (11)

Dangers of Dry Cask Storage

A few of the 28 permanently shutdown commercial reactors have had all their irradiated fuel transferred into on-site outdoor dry casks, followed by the dismantling of the pools themselves (thus leaving nowhere to handle the intensely radioactive fuel should an emergency situation develop with a loaded dry cask). A growing number of storage pools at operating reactors have already filled to capacity, leading to the establishment of "Independent Spent Fuel Storage Installations" (ISFSIs), which are arrays of dry casks sitting in the open air, congregated in rows on parking lot-like concrete pads at the reactors where the wastes were generated. By 2015 nearly all U.S. reactors' irradiated fuel storage pools will be filled to capacity. (12) Already, a total of 36 nuclear power plant sites have 762 dry casks fully loaded with irradiated nuclear fuel stored on site; 13 additional nuclear power plant sites are in process of installing dry cask storage installations. (13) Thus, the growing trend is for operating reactors to install dry cask storage on-site when their storage pools are overflowing with waste.

NRC-approved technical specifications require irradiated fuel to thermally cool and radioactively decay for at least five years underwater before the waste can be loaded into a dry cask (although NRC has granted exemptions to violations of such "tech specs" after the fact, as at Palisades in 1999). Thus, the most cooled and decayed fuel in a pool is often loaded into dry casks first. Operating plants transfer their older fuel assemblies into dry casks to free up space in the pools so that newly discharged fuel from the reactor core can begin its minimum five-year cool down underwater.

Some assert that dry cask storage is safer than pool storage. (14) For example, unlike pools, dry casks have no moving parts that can fail, instead relying on natural convection currents flowing through cask vents to keep the waste from overheating. In addition, as opposed to densely packed pools, which can contain all the irradiated fuel ever generated by a reactor in one location, dry casks force the placement of a plant's high-level waste stockpile into smaller, discrete amounts. Whereas a single accident or attack could involve the entire massive amount of waste contained in a pool, an accident or attack involving a single dry cask would involve only a fraction of a plant's irradiated fuel.

However, while dry cask storage may have some advantages over pools, it is far from safe and since waste cannot be taken immediately from the reactor core and put into dry casks, the use of pools cannot be eliminated for operating reactors. In just the first two decades of dry cask storage in the U.S., nuclear utilities have amassed a troubling history of accidents and incidents. (15)

For example, a hydrogen gas explosion within a dry cask at the Point Beach, WI nuclear plant in 1996 was forceful enough to dislodge a 4,000 pound cask lid several inches ajar, endangering workers and risking damage to the fuel within the cask, fuel in the pool below, or even a drain down of the pool itself. There have been repeated violations of quality assurance and control, and shoddy workmanship, during cask design and manufacture, resulting in defects that call the structural integrity of the containers into question. There has been no demonstrated safe unloading procedure for faulty dry casks. Dry casks, and the concrete pads they sit upon, violate NRC regulations but the Commission grants exemptions and deferments and continues to allow the faulty ISFSIs to be loaded and deployed. Dry cask storage at certain locations in the U.S. is vulnerable to the potential rising of sea levels due to global warming, flooding rivers, or eroding lakeshores. The long-term integrity of the irradiated fuel within dry casks is of concern, as it can reach temperatures of over 400 degrees Fahrenheit, as opposed to the 100-degree temperature maintained in "wet" pools. The eventual degradation of the dry casks themselves is an issue, risking the corrosion and deterioration of the waste inside over time, thus complicating and worsening the dangers of all future handling and storage of the irradiated fuel.

In addition to slow leaks or sudden accidents, dry casks are also vulnerable to terrorist attack. Kept outdoors and concentrated in tight rows in plain view, dry casks are easily identifiable and potential targets for attacks using remotely fired anti-tank missiles or other special weaponry, such as high explosives or shaped charges. A 1998 experiment at the U.S. Army's Aberdeen Proving Ground in Maryland showed that a TOW anti-tank missile was able to pierce a grapefruit sized hole through the side of a German CASTOR dry storage cask, considered by some to be the "Cadillac" of dry casks because of its 15-inch-thick cast iron walls. (16) Most U.S. dry casks, on the other hand, have at most a few inches of steel. Although concrete two feet or thicker is used to surround many U.S. dry casks as a radiation shield, anti-tank missiles easily obliterate this, as the Aberdeen test also showed. Thus, if terrorists had multiple missiles, they could defeat the concrete shield and internal metallic container of U.S. casks. Combined with an incendiary device, large amounts of radioactivity could be dispersed downwind through a high-temperature, long-duration fire. Like pools, ISFSIs are currently pre-deployed weapons of mass destruction awaiting detonation by a terrorist attack.

Given the vulnerabilities to terrorist attack, a coalition of environmental and public interest groups has called for "hardened" or "robust" ISFSIs - fortification or bunkering of dry casks behind thick layers of concrete, steel, and gravel. There have also been calls for "dispersing" casks - separating them at a distance from one another - so that even a large-scale explosive attack would involve only a limited number of fortified dry casks. (17) Despite such calls, NRC and the nuclear utilities themselves have taken no such actions, leaving ISFSIs vulnerable to attack.

Dangers of Transportation
There have been many calls from the nuclear power industry and its backers in government to transport irradiated nuclear fuel and high-level waste on U.S. roads, rails, and waterways. Many politicians and utilities have embodied NIMBY-ism (Not In My Back Yard) by advocating YIYFY-ism (Yes In YOUR Front Yard), targeting dumps at Yucca Mountain, Nevada (90 miles northwest of Las Vegas, the fastest growing city in the U.S.) and Skull Valley, Utah (45 miles upwind of the Wasatch Front and Salt Lake City, where much of the state's population lives).

The Private Fuel Storage (PFS) plan targeting Utah would launch 4,000 rail shipments to Skull Valley over a 20-year period. The Yucca Mountain Project could involve over 50,000 truck shipments, 10,000 rail shipments, and even 1,600 barge shipments on the Great Lakes, seacoasts, and numerous rivers. (18) Such proposals dwarf the total number - 2,500 to 3,000 - of irradiated fuel shipments that have taken place in the U.S. since the dawn of the Atomic Age 63 years ago. Even the limited experience of such shipments in the U.S. has seen numerous incidents and accidents, including radioactive leaks beyond the vehicle, as well as over 50 instances of shipments radioactively contaminated on the exterior of the shipping container, endangering not only workers, but also the general public. (19)

Shipping is probably the weakest link in the entire chain of irradiated nuclear fuel management. Waste going zero miles per hour in pools or dry casks is dangerous enough, but waste going 60 miles per hour or faster on the roads and rails introduces new and greater accident risks. Severe crashes, or long-lasting, high-temperature fires - all too common in real world accidents - could breach the shipping containers, releasing catastrophic amounts of radioactivity. Underwater submersion - involving a sunken barge or a shipment plunging off a bridge - could lead to contamination of drinking water, or even an accidental nuclear chain reaction due to leakage of neutron-moderating water into the fissile radionuclides still present in the waste. The National Academy of Sciences recently advised that fiery accident scenarios need more study. (20)

In addition, while irradiated fuel is almost never stored in downtown metropolitan areas (with the exception of a small number of research reactors at certain universities), during transport high-level atomic waste would travel right through the heart of hundreds of cities. This presents would-be attackers with a high profile opportunity to cause a catastrophic radiation release in a population center.

As mentioned above, conservative estimates reveal that each truck cask on the highways would carry up to 40 times the long-lasting radioactivity released by the Hiroshima atomic bomb. Rail and barge casks, six times larger, would carry over 200 times the long-lasting radiation released at Hiroshima. Release of even a fraction of this cargo would spell unprecedented radiological disaster. A study of a real world transport accident - a train fire in a tunnel beneath downtown Baltimore that burned, initially at very high temperatures, for several days in July 2001 - revealed that if just one train car load of irradiated nuclear fuel had been aboard, its shipping container would have failed and large amounts of radioactivity would have escaped for miles downwind in the billowing smoke clouds. Hundreds of thousands of Baltimore residents would have been exposed to the escaping radioactivity. Nearly US$14 billion would have been required for clean up, or else thousands would have died from cancer after living amidst the contamination for just one year; living amidst the fallout for 50 years would have resulted in over 30,000 latent cancer fatalities. (21)

Thus, given the potential for severe accidents or attacks, these shipments represent "Mobile Chernobyls" and "dirty bombs on wheels" rolling through our communities. These risks are made all the worse because emergency responders nationwide - especially volunteer fire departments along vast stretches of the interstates and railways across the country - are neither adequately trained nor equipped to deal with radiological releases. Although the federal Yucca Mountain plan involves a token, inadequate funding mechanism to pay for such emergency preparedness, the industry's PFS plan does not even contain that.

But even "incident-free" shipments are like mobile x-ray machines that cannot be turned off. NRC regulations allow for irradiated nuclear fuel shipping containers to emit 10 millirems per hour of gamma radiation (the equivalent of a chest x-ray) to persons standing six feet away; casks are permitted to give off 200 mrem/hr (equal to 20 chest x-rays) at their surfaces. (22) Thus, nuclear workers, truck drivers, locomotive engineers, railroad workers, inspectors, toll booth attendants, gas station employees and customers, innocent bystanders at rest areas, residents living along transport routes, and unsuspecting passersby on the highways all face radiation doses if they come too close to such shipments. If casks are externally contaminated with radioactivity, as has been documented scores of times in the U.S., and hundreds of times during shipments in Europe, then "routine" doses to the general public will be even worse. In 1997 and 1998, activists and investigative reporters revealed that 20-37 percent of all shipments into France's reprocessing facility were externally contaminated above regulatory limits - many emitting 500 times the permissible dose, and one emitting 3,300 times the permissible dose! (23) The National Academies of Science's BEIR VII report (Biological Effects of Ionizing Radiation) in 2005 re-affirmed that any dose of radiation, no matter how small, could inflict a negative health impact. (24)

Due to such shipping dangers, as well as resistance to proposed dumps, large-scale popular protests have erupted against irradiated fuel shipments. In Germany, tens of thousands have come out to block transports, sitting in roads and locking themselves to train tracks. In 1997, the German government deployed 30,000 police to guard a convoy of just six casks, costing US$100 million. (25) Such protests are likely in the U.S. should proposed high-level waste dumps be opened and large-scale waste transports begin.

To see how close to a certain address is to targeted high-level radioactive waste transport routes to Yucca Mountain, go to http://www.ewg.org/reports/nuclearwaste/find_address.php.

The Dangers of Reprocessing

A concerted effort is underway by the Bush Administration, some members of Congress, the Department of Energy (DOE), and certain segments of the nuclear industry, to revive commercial irradiated fuel reprocessing in the U.S. for the first time in over 30 years. The effort seems like a desperate clutching at straws for a nuclear waste "solution" in the face of the recent major setbacks to the Yucca Mountain and Skull Valley dump proposals (see below). Such a reprocessing relapse significantly threatens worker and public health, endangers the environment, and risks nuclear weapons proliferation.

Reprocessing involves the physical chopping up of irradiated nuclear fuel assemblies, which are then dissolved in hot, concentrated nitric acid in order to extract still-fissile uranium and plutonium, supposedly for re-use as nuclear reactor fuel. Reprocessing inevitably results in the creation of extremely large volumes of liquid high-level radioactive waste, which is significantly more difficult to prevent from leaking into the environment than is solid irradiated nuclear fuel, which is troublesome enough in its own right. Even if reprocessing goes according to plan, it results in significant "routine" liquid and gaseous releases of radioactivity into the environment, as well as high worker and public radiation doses.

Both Republican and Democratic presidential administrations have seen commercial reprocessing as a mistake. President Gerald Ford instituted a ban in October 1976, which Jimmy Carter endorsed, strengthened and extended in April 1977, citing commercial reprocessing as risking the proliferation of nuclear weaponry around the world. (26) Although Ronald Reagan overturned the reprocessing ban in the early 1980s, the high cost of fabricating nuclear reactor fuel from reprocessed commercial wastes as compared to using raw uranium straight from the mines has meant no revival of reprocessing in the U.S. to date.

Earlier attempts at commercial reprocessing in the U.S. ended in dismal failure. In addition, so-called "interim" irradiated fuel storage at reprocessing facilities has actually become de facto long-term, even permanent, storage in some cases.

General Electric's reprocessing facility in Morris, Illinois was built and opened in the early 1970s but never operated due to major equipment failures and technical problems. However, the 772 tons of high-level radioactive commercial waste stored underwater remain there to this day. Recently, NRC extended that facility's original operating license for another 20 years, until 2022. Thus a proposed reprocessing facility has instead become a several-decades-long storage site for commercial high-level radioactive waste from reactors from several states. A completely built commercial reprocessing facility in Barnwell, South Carolina was never operated due to the Ford/Carter nonproliferation ban on reprocessing, and because studies showed that the facility had unacceptable design, operational, and maintenance risks. (27)

The only actual U.S. operational experience with commercial reprocessing took place at West Valley, New York. The West Valley reprocessing center operated from 1966 to 1972. It reprocessed only about one-sixth of its design capacity for irradiated fuel due to chronic equipment breakdowns and accidents involving radioactive contamination. Thus, only about one year's worth of projected irradiated nuclear fuel output was actually reprocessed in six years of operations. The last un-reprocessed irradiated fuel was not removed from the site until 2003, and vitrified (glassified) logs of highly radioactive waste still remain at the site, 40 years after its opening and 33 years after the cessation of reprocessing operations. In addition, high-level radioactive sludge remains in the underground storage tanks, threatening eventual leakage into Lake Erie. (28)

Reprocessing is ruinous for the environment. Despite only reprocessing 27 "runs" of irradiated fuel - an amount that was supposed to have been completed in the first year of operations - West Valley suffered severe radioactive contamination. There were fires, high worker exposures and radioactive releases into the water and the air - some of which left a radioactive "prong" of contamination identifiable decades later by aerial surveying. According to DOE, the clean up bill for the mess made by these minimal reprocessing operations at West Valley is projected to cost over US$5 billion of taxpayer's money (in 1996 dollars; adjusted for inflation, the clean up bill has now surmounted US$6 billion). (29)

Reprocessing advocates have touted the European reprocessing model as one for the U.S. to follow. But according to a 2001 report published by the European Parliament's Scientific and Technological Options Assessment, 80 percent of the collective radiation dose of the entire French nuclear power industry, and 90 percent of the radioactive emissions and discharges from the British nuclear power program, come from commercial waste reprocessing. The collective radiation dose from 70 years of "routine" (that is, accident-free) operations of the French and British reprocessing plants would be equivalent to the collective radiation dose from the Chernobyl nuclear catastrophe. Toxic chemicals used in these reprocessing facilities, in addition to the radioactive discharges, are also potentially harmful to human health. (30)

The British reprocessing center at Sellafield has discharged over 1,000 pounds of plutonium - known to be carcinogenic in microscopic quantities if inhaled or ingested - into the sea, which has been detected in children's teeth throughout the British Isles. The plutonium concentration in children's teeth decreases with distance from Sellafield, an indication that releases from the reprocessing facility is to blame. (31) Radioactive contamination of the seafood supply has caused downstream governments from Ireland to Scandinavia to protest at the large-scale radioactive discharges into the ocean. (32)

Sellafield's workforce has been the most highly exposed to radioactivity when compared to the rest of Western Europe and North America. A study has found a significant, positive association between a father's preconception ionizing radiation exposure and the stillbirth of his child. Yet another study has found that male Sellafield workers' exposures increase their children's risk of leukemia and non-Hodgkin's lymphoma. (33)

A large accidental leak of highly radioactive liquids containing 20 tons of uranium and enough plutonium to make 20 nuclear warheads that occurred on April 19, 2005 threatens to permanently close Britain's US$3.8 billion reprocessing facility. (34)

The La Hague reprocessing facility located on the Normandy coast is owned and operated by the French government. The seafloor sediments beneath the pipeline dumping radioactive liquid wastes from La Hague into the English Channel are so contaminated that, under British law, they would be classified as "intermediate level wastes," requiring special handling and deep geologic disposal. (35) A study of the population around La Hague has found an increase in childhood leukemia. However, this increase was associated with the radioactive pollution of the environment around the facility, not paternal radiation exposure of workers as at Sellafield. Consumption of local fish and shellfish, as well as mothers and children visiting the local beaches, have been associated with increased risk of contracting leukemia. A subsequent study verified an increase of leukemia among children under the age of ten within ten kilometers (6.6 miles) of the facility, especially lymphoblastic leukemia. (36)

Although increases of childhood diseases and stillbirths have been found in populations around both Sellafield and La Hague, some researchers question whether the maladies have come from plant workers suffering radiation-induced gene mutations that later damage their offspring, or whether parents' and children's direct exposure to radiation in the environment is the culprit. Regardless of the pathway by which the radiation has traveled to cause this health damage, elevated levels of certain childhood diseases and stillbirths are present around these currently operating reprocessing facilities in Europe.

Incredibly, the supposed reason for reprocessing commercial wastes in the first place - "recycling" the fissile plutonium and uranium - has largely fallen apart, as shown by the failure of France's "Superphenix" plutonium breeder reactor. Thus, both France and Britain have mounting stockpiles of separated, weapons-usable plutonium with nowhere to go.

Commercial reprocessing in Britain, France, and the U.S. sets an example for other countries to follow. Those countries might then choose to channel their separated plutonium into nuclear weaponry. India secretly reprocessed the wastes from its "Atoms for Peace" reactors, and then used the separated plutonium to explode its first nuclear weapon in 1974. In fact, India's nuclear detonation is what led President Ford to ban commercial waste reprocessing in the U.S. as a non-proliferation safeguard. Reviving reprocessing in the U.S. invites nuclear weapons proliferation around the world.

Military reprocessing to extract plutonium from irradiated fuel generated in DOE reactors for nuclear weapons purposes in the U.S. has likewise caused severe radioactive contamination and the build up of troublesome liquid high-level radioactive wastes at such sites as the Hanford Nuclear Reservation in Washington State, the Idaho National Lab (INEL), and the Savannah River Site (SRS) in South Carolina. Many hundreds of gigantic belowground storage tanks hold huge volumes of intensely radioactive liquids and sludges at these three sites. A significant number of these tanks have already leaked their contents into the ground, threatening local groundwater, such major rivers as the Columbia and Savannah, and such major aquifers as the Snake and Tuscaloosa. In addition, the DOE plan to permanently abandon high-level radioactive sludges in the tanks at INEL and SRS by pouring concrete grout on top of them, sponsored in the U.S. Senate by Lindsay Graham (Republican-South Carolina), threatens to severely contaminate the Snake River Aquifer, Savannah River, and Tuscaloosa Aquifer as the metallic tanks corrode, the concrete grout deteriorates, and the radioactive sludges flow into the waterways over time. If just a fraction of the radioactive strontium (one of hundreds of radioactive poisons present) leaks into the Savannah River from SRS's reprocessing sludges, the river water will violate the Safe Drinking Water Act. (37)
DOE's sludge abandonment policy seriously threatens public health and the environment downstream from INEL and SRS. Attempts to vitrify the high-level liquid wastes at these reprocessing facilities have encountered many difficulties. There is the

added concern that vitrified liquid wastes, due to the high thermal heat and intense radioactivity, will break down over time once buried in a repository, leading to massive radioactive leakage at such sites as Yucca Mountain. (38) The total cost of cleaning up the radioactive messes caused by military reprocessing could reach into the tens or even hundreds of billions of dollars. The amount of health and genetic damage inflicted on workers and the public downwind and downstream of these facilities, although substantial, may never be fully known. (39)

Ironically, because military irradiated nuclear fuel spends much less time undergoing fissioning inside reactors than commercial irradiated fuel does, military irradiated fuel contains significantly less radioactivity than commercial waste. In addition, a much larger quantity of commercial irradiated fuel has been generated in the U.S. than military irradiated fuel. Thus, the high costs, environmental degradation, and health damage caused by military reprocessing could be far surpassed by full scale commercial waste reprocessing.

The Failures of "Interim" Storage

The nuclear establishment has continuously sought to open national or regional "interim" storage sites - essentially surface parking lots, huge away-from-reactor ISFSIs - for commercial irradiated nuclear fuel. Shamefully, both government and industry, in a blatant example of environmental racism, have targeted mostly Native American reservations. (40)

The U.S. government established the Office of the Nuclear Waste Negotiator within DOE from 1987 to 1994. Despite actively targeting dozens of tribal reservations for "temporary" dumps, and offering hundreds of thousands to millions of dollars to these often low-income communities of color, the Negotiator failed to open a "Monitored Retrievable Storage" (MRS) site. This hard won environmental justice victory was largely due to the determined efforts of traditional activists within the targeted communities, such as Grace Thorpe at Sauk and Fox Reservation in Oklahoma and Rufina Marie Laws at Mescalero Apache Reservation in New Mexico, aided by grassroots environmental allies throughout the country.

The nuclear industry picked up where the Negotiator left off. A consortium of nuclear utilities formed Private Fuel Storage, LLC (PFS) in 1994. PFS first attempted to ram through a dump targeted at Mescalero Apache Reservation but when popular resistance proved too strong there, PFS shifted to targeting the tiny (120 member) Skull Valley Band of Goshutes Indian Reservation in Utah. The Goshute community has suffered the trauma of being targeted by this dump ever since. (41)

Margene Bullcreek, founder of Ohngo Gaudedeh Devia ("Timber Setting Community," in Goshute), has led the resistance to the dump on the Skull Valley reservation. The State of Utah led the fight against the PFS proposal during the NRC licensing proceeding. The 1997 to 2005 proceeding culminated in split-decision approvals for the license by NRC's Atomic Safety Licensing Board (two to one vote) and Commission (three to one vote). The main controversy involved the adjacent Utah Test and Training Range, one of the biggest and busiest U.S. Air Force bombing and missile test ranges in the country. Seven thousand F-16s fly over Skull Valley every year. The lone engineer on the licensing board warned that the lack of adequate crash data, and risk of design and manufacturing errors on the Holtec dry casks to be used at PFS, prevented him from agreeing that an accidental F-16 fighter jet crash into PFS would not release radiation in excess of NRC standards. Nuclear safety whistleblower Oscar Shirani, fully supported by retired NRC dry cask inspector Dr. Ross Landsman, alleges that Holtec casks suffer just such serious quality assurance violations. (42) NRC Commissioner Gregory B. Jaczko also voted against granting PFS a license. (43)

The State of Utah tried to raise the issue of deliberate terrorist attack against PFS during the proceeding. But not only has NRC refused to take action against such threats, in December 2002 it forbade states, environmental groups, and concerned citizens from raising such security issues in all future licensing procedures. (44)

Utah, and its federal congressional delegation, has fought PFS at every turn. In December 2005, the Utah congressional delegation succeeded in establishing a federal wilderness area in Skull Valley that effectively blocks PFS's preferred rail route extension for delivering irradiated fuel to the Goshute Reservation. (45) In addition, U.S. Senator Orrin Hatch of Utah pressured several PFS member utilities, including major shareholder Xcel Energy of Minnesota, to pledge not to fund PFS past the licensing stage. (46) Such blows may not kill PFS outright, but they represent major nails in the coffin.

In addition to Native American reservations, proponents of the permanent burial site at Yucca Mountain tried from 1995 to 2000 to open so-called "interim" dry cask storage at the Nuclear Weapons Test Site right next door, a naked attempt to shove the proposed repository down Nevada's throat long before the site characterization studies were finished. President Clinton's veto, sustained by a veto-proof margin in the U.S. Senate, assured by Nevada's tireless congressional delegation and the united U.S. environmental movement, stopped "interim" storage in Nevada time and time again - a major grassroots environmental victory over the powerful nuclear establishment.

The Failures of "Permanent Disposal"

Politics, not science, has driven the Yucca Mountain Project from the very beginning. Yucca was singled out for the country's first repository not because it had suitable geology, but rather because Nevada was seen as a politically vulnerable state. In fact, from 1987 until today, safety and environmental protection regulations have been repeatedly weakened or eliminated altogether to keep the ill-conceived, dangerous Yucca proposal afloat. (47)

Yucca is very seismically active. Nevada is the third most earthquake-prone state after Alaska and California. Between 1976 and the late 1990s, over 600 earthquakes, registering 2.5 or greater on the Richter scale, struck within 50 miles of Yucca. In 1992, a 5.6 quake with its epicenter just 10 miles from Yucca did extensive damage to DOE's field office there. Thirty-three fault lines have been identified within and adjacent to Yucca Mountain. All this earthquake activity has fractured and fissured Yucca's geology, creating pathways for radioactive gases and water-borne radioactive particles to leak out of the dump into the environment. Yucca could also face catastrophic risks associated with volcanic activity. (48)

In the early 1990s, it was determined that Yucca would violate EPA's generic repository standards in terms of how many people downwind would be killed by escaping radioactive gases such as very long-lasting carbon-14. In response, the U.S. Congress, under pressure from the nuclear power industry, DOE, and the first Bush Administration, passed amendments to the Nuclear Waste Policy Act (NWPA) of 1982 that ordered EPA to set site-specific standards applicable only to Yucca, thereby "getting around" the deadly gaseous releases. (49)

By 1997, it was determined that in less than 50 years, rainwater had percolated down through fractures and fissures at Yucca all the way to the proposed repository level 800 feet beneath the mountain's crest (this is a mere 120 feet beneath the valley surface adjacent to Yucca). Thus, in just decades or at most a few centuries, infiltrating rainwater could corrode waste burial containers, release radioactivity, and carry it downstream to the farming community of Amargosa Valley, Nevada. There, it could be ingested as drinking water, or in animal products and crops that would biologically store radioactivity from Yucca groundwater used for irrigation. (50)

The fast flow rate of water through the Yucca site violated DOE's own Site Suitability Guidelines, established in 1984. The relevant guideline held that a proposed repository must be disqualified if water flowed through its geology and back out into the living environment in less than a thousand years. In late 1998, over 200 environmental and public interest groups petitioned DOE to disqualify Yucca based on this fast flow rate of water. (51) DOE responded that it needed more time for scientific studies. However, in 2001, DOE simply did away with its 17-year-old Site Suitability Guidelines altogether, again "getting around" the fast flow rate of water. (52) Less than a month later, DOE declared Yucca suitable for development as a repository. In 2005, the State of NV discovered 'smoking gun' emails written by U.S. Geological Survey scientists working at Yucca that appear to show falsification of data regarding the vital issue of water infiltration and hydrology. (53)

Dr. Arjun Makhijani, who served on EPA's advisory panel for generic repository regulations in the 1980s, refers to such rollbacks of environmental protections at Yucca as "double standard standards." Although he favors deep geologic burial as the best alternative, he opposes Yucca because it is amongst the worst geology in the country that could have been chosen. (54)

The Yucca Mountain Project suffered another major blow in July 2004 when the U.S. Court of Appeals for the D.C. Circuit ruled in favor of the State of Nevada and a coalition of environmental groups, including NIRS, that the EPA's arbitrary cut off of radiation regulations at 10,000 years post burial was illegal. The Court ordered EPA to re-write its Yucca regulations so that they protect public health out to the period of peak dose downstream. (55) Although EPA's revised rule now purports to regulate radioactivity out to a million years post burial, the proposal would allow for radiation doses at least 23 times higher for future generations than would be allowed for current generations. This would result in a 1 in 36, or even worse, cancer rate due to Yucca's leaking wastes. Such a disastrously weak regulation would almost certainly lead to another court challenge. (56)

The NWPA mandated that DOE begin accepting wastes at a national repository by January 31, 1998. This proved to be impossible, as Yucca was not even approved to enter its licensing phase - by Congress and George W. Bush, overriding Nevada's veto - until 2002. DOE was then supposed to submit its Yucca license application to NRC by October 23, 2002 but this did not happen and has not happened to date as delays continue to plague the project.

In 2001, DOE had to fire its legal counsel, Winston and Strawn, when it was revealed that contract lawyers preparing DOE's license application to NRC were simultaneously lobbying Congress on behalf of the Nuclear Energy Institute for the approval of Yucca. DOE is already over three years late in filing its license application, and recent statements indicate DOE cannot apply until 2007 at the earliest. NRC's licensing proceeding would take at least an additional 3 to 4 years.

The State of Nevada has numerous lawsuits pending against the project and appears determined to fight Yucca in the courts at every opportunity. One suit challenges the proposed 320-mile-long railway needed to deliver the wastes to Yucca. (57) This rail construction would be the largest such project in the U.S. since World War Two; DOE first estimated it would cost US$880 million, but has recently raised its projection to US$2 billion. (58) DOE has already spent US$6 billion at Yucca and recently admitted that the total costs could reach nearly US$60 billion if the Project goes to completion. But it appears that the actual price tag could be substantially more than that already stunning figure. The Nuclear Waste Fund Fee of nuclear utility ratepayers will generate only about half of the US$60 billion; the shortfall would have to be appropriated by Congress, yet another unique and unprecedented subsidy to the nuclear power industry at the expense of the federal taxpayer. (59)

The earliest Yucca could open is 2012 although more conservative estimates suggest 2020. Its projected budget for Fiscal Year 2007 is US$544.5 million, as compared to predictions just three years ago that by now, Yucca's annual budget would surpass US$2 billion. Congress seems to be losing faith in Yucca ever opening. (60)

DOE, for its part, has announced in recent months a major design overhaul for the repository, guaranteed to prolong the delays for additional years. (61) In December 2005, DOE placed a Stop Work Order on Bechtel-SAIC due to major quality assurance problems identified by whistleblowers. (62) In a surprise move, DOE has now decided not to grant Bechtel-SAIC a five year renewal on its management contract at Yucca due to expire in March 2006, guaranteeing additional delays as Sandia National Laboratory takes over many aspects of Yucca's management. (63) Significantly, another National Lab - Los Alamos - reported in the mid 1990s that so much fissile material could leak out of waste burial containers within Yucca Mountain that a critical mass, inadvertent nuclear chain reaction, and even an atomic explosion could result. This would cause catastrophic radiation releases into the environment. (64) In addition to its scientific, political, and legal woes, Yucca Mountain is sacred to the Western Shoshone Indian Nation, and is located on their un-ceded homelands, as affirmed by the Treaty of Ruby Valley signed by the U.S. government in 1863. The tireless Western Shoshone National Council has vowed to continue fighting for its land rights and against this environmentally racist nuclear waste dump in U.S. courts and international forums. (65)

The Future: Alternatives and Solutions

The only real solution for the high-level radioactive waste dilemma is to stop making such wastes in the first place. Dangerous, dirty, and deteriorating nuclear power plants must be phased out as quickly as possible. They can be replaced by energy conservation, energy efficiency, and renewable sources of electricity such as solar and wind power.

DOE has predicted that if the 103 commercial reactors operating in the U.S. each continue generating irradiated fuel for 50 years, the quantity of commercial high-level radioactive waste currently in the U.S. (just over 50,000 metric tons) will double by 2046 (to 105,000 metric tons). (66) However, NRC has rubberstamped permission for 37 reactors to operate for a total of 60 years, and many other reactors are lining up for such license extensions. (67) Thus, another decade worth of irradiated fuel generation at each reactor not accounted for by DOE's prediction could occur, representing tens of thousands of additional tons.

In addition, any new reactors built in the U.S. would add to that mountain of radioactive waste. If old and new reactors keep churning out irradiated fuel, the mountain of high-level radioactive waste in the U.S. could even triple its current size. Enough commercial irradiated nuclear fuel - 63,000 metric tons - will exist in the U.S. by 2010 to fill Yucca to its legal limit. Thus, any and all waste generated after that would be in excess of Yucca's capacity, assuming that it opens someday. (68)

A second national repository would be needed and according to the NWPA, this would have to be located in the eastern U.S. In the mid 1980s, DOE investigated sites in Minnesota, Wisconsin, New Hampshire, Virginia, North Carolina, Mississippi, and other eastern states. DOE is supposed to report to Congress and the President by 2010 on the need for a second repository. (69) DOE Deputy Secretary Clay Sell recently told a U.S. Senate Energy and Natural Resources Committee that as many as nine Yucca Mountain-type repositories could be needed in the U.S. alone under the Bush administration's Global Nuclear Energy Partnership, which includes the possibility of importing other countries' commercial irradiated nuclear fuel. (70)

But what can be done about the over 50,000 metric tons of commercial irradiated fuel that already exists in the U.S.? Almost all of it is still stored at the reactors where it was generated but these are located, in many instances, on seacoasts, rivers and lakes. The effects of global warming - rising sea level, and worsening natural disasters such as hurricanes - threaten coastal nuclear plants and the wastes stored there with flooding. The erosion of lakeshores and flooding rivers also threaten inland reactors and their stored wastes. In certain instances, it may be prudent to move wastes a short distance inland or to higher elevation in order to protect against flooding. But the transport of irradiated fuel must be minimized, due to the additional risks it introduces - moving wastes even a short distance raises the problem of contaminating a new location with radioactivity.

Pools are vulnerable to accidents and attacks, and require constant cooling water circulation over the irradiated fuel to prevent catastrophe. In addition to permanently shutting down reactors, pools should be emptied of the wastes within them as soon as possible (irradiated fuel must cool in pools for five years before it can be transferred to dry storage casks). However, pools should not be dismantled, but rather maintained as a place for waste to be returned to if there is a mishap involving dry storage casks. If pools are dismantled at permanently shut down reactors, a dry cell must be built on site for remote handling and radiation shielding in the event of emergencies involving dry casks.

The reality staring us in the face is that irradiated nuclear fuel will likely remain right where it is - at the reactor sites where it was first generated - for many decades to come. Thus, current methods of dry cask storage must be significantly improved to prioritize safety and security. To guard against terrorist attacks using remotely fired armor-piercing missiles, shaped charges, or other high explosives, dry casks must be fortified or bunkered behind concrete, steel, and/or other defensive structures. Line-of-site attacks must be blocked, such as by building earthen berms (banks) or warehouses around the dry casks. Casks must also be dispersed with distance, so that no single terrorist attack - even one involving a nuclear weapon or other very large explosive - could result in the discharge of all the irradiated fuel into the environment.

To safeguard against accidents involving dry casks, their design and manufacture must be drastically improved. Completely independent third parties must rigorously enforce quality assurance and quality control measures since the industry and NRC have shown they cannot be trusted to do the job. Radiation monitors and temperature controls must be affixed to all dry casks to watch for leaks or overheating due to blocked airflow. Casks must be inspected regularly for signs of deterioration as well as for blockage of air vents by blowing debris or wildlife building nests, risks that could be largely eliminated by putting casks indoors.

Depending on how long waste is stored in casks, it is likely that containers will degrade with age and have to be replaced with brand new casks in future. Irradiated fuel must be monitored in a retrievable fashion so that it can be re-packaged as time goes on, to prevent leakage of radioactivity into the environment. Inadvertent nuclear chain reactions in the fissile materials still in the waste must also be guarded against forevermore into the future. The integrity of fuel rods within dry casks must also be monitored. The more fuel rods deteriorate over time, the more difficult and dangerous it will become to handle, transport, and store them. Efforts must be made to prevent deterioration of irradiated nuclear fuel.

Transport casks must undergo full-scale physical safety testing to destruction, and be designed and manufactured to survive real-world accidents such as long-lasting, high-temperature fires, high-speed crashes, drops from elevations such as bridges or cliffs, and long-duration, deep underwater submersions, as well as an array of potential terrorist attacks. First responders and hospitals across all states targeted for high-level radioactive waste shipments must be trained and equipped to deal with large-scale radiological emergencies.

For worker and public health protection, to prevent environmental devastation, to avoid nuclear weapons proliferation, and to avoid wasting astronomical amounts of money, reprocessing must be prohibited. Environmentally racist attempts at dumping, such as targeting Native American and other people of color and low income communities for so-called "interim" storage of irradiated fuel, must cease.

In terms of proposals for deep geologic storage, a scientifically sound, socially acceptable, and environmentally just program must be established. (71) Stable geology that can isolate the massive amounts of deadly radioactivity for as long as it will remain hazardous - millions of years - is required. Zero radiation release into the biosphere is the goal. The politically driven Yucca Mountain Project fails all such tests, and must be stopped.

The astronomical amounts of ratepayer and taxpayer money saved by halting the Yucca Mountain Project and such dirty and dangerous proposals as reprocessing can be much better invested into implementing better ideas such as those described here.

NIRS and many other groups have long called for a completely independent Blue Ribbon Commission, not beholden to the nuclear establishment in industry and government, to identify the most safe and sound methods for nuclear waste management, keeping in mind that the initial creation of nuclear waste is fundamentally unsafe and unsound. As much scientific and social effort and resources as were put into the Manhattan Project that initiated the creation of our radioactive waste dilemma needs to be invested in the management of high-level radioactive wastes. (72)

The myth of "disposal" must be debunked. Irradiated fuel and high-level radioactive wastes will have to be managed in perpetuity to prevent catastrophic leakage of radioactivity into the environment.

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(62) See http://www.reviewjournal.com/lvrj_home/2006/Jan-06-Fri-2006/news/5232916.html.
(63) See http://www.reviewjournal.com/lvrj_home/2006/Jan-21-Sat-2006/news/5470852.html.
(64) Broad, William J., "Scientists Fear Atomic Explosion of Buried Waste," New York Times, March 5, 1995.
(65) See http://www.wsdp.org/.
(66) DOE Yucca FEIS, Tables A-7 and A-8, February 2002.
(67) See http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html.
(68) DOE Yucca FEIS, Tables A-7 and A-8, February 2002.
(69) The Nuclear Waste Policy Act, as Amended, Subtitle E-Redirection of the Nuclear Waste Program, Selection of Yucca Mountain Site, Sec. 161, subpart (b), which reads: "Report. The Secretary shall report to the President and to Congress on or after January 1, 2007, but not later than January 1, 2010, on the need for a second repository."
(70) DOE handout, "The Key Elements of the Global Nuclear Energy Partnership," brought by DOE Deputy Secretary Clay Sell to the Senate Appropriations Committee, Energy and Water Subcommittee, hearing chaired by U.S. Senator Pete Domenici (Republican-New Mexico) on March 2, 2006-hardcopies available upon request from Kevin Kamps, at NIRS, kevin@nirs.org.
(71) See for instance, Arjun Makhijani and Scott Saleska, "High-Level Dollars, Low-Level Sense: A Critique of Present Policy for the Management of Long-Lived Radioactive Waste and Discussion of an Alternative Approach," IEER, New York, New York: The Apex Press, 1992; also IEER, Science for Democratic Action newsletter, "IEER's Plan for Management of Highly Radioactive Waste," Vol. 7, No. 3, May 1999, at http://www.ieer.org/sdafiles/vol_7/7-3/index.html; for principles of environmental justice, see the websites of the Center for Health, Environment and Justice (http://www.chej.org/) and the Indigenous Environmental Network (http://www.ienearth.org/), as well as http://www.ejnet.org/ej/.
(72) See http://www.nirs.org/factsheets/indcomm.htm.

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WISE AMSTERDAM/NIRS

ISSN: 1570-4629

Editorial team: Tinu Otoki and Peer de Rijk (WISE Amsterdam), Michael Mariotte (NIRS).

With **contributions** from NIRS.

The next issue (644) will be mailed out on April 22, 2006.

WISE/NIRS NUCLEAR MONITOR

The Nuclear Information & Resource Service was founded in 1978 and is based in Washington, US. The World Information Service on Energy was set up in the same year and houses in Amsterdam, Netherlands. NIRS and WISE Amsterdam joined forces in 2000, creating a worldwide network of information and resource centers for citizens and environmental organizations concerned about nuclear power, radioactive waste, radiation, and sustainable energy issues.

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