The Other Arms Race: The Liquid Metal Fast Breeder Reactor and the Plutonium Safeguards Problem

The development of breeder reactors that produce more fuel than they consume should be accelerated as a means of reducing the costs and hazards of nuclear power.

-Southern Governor's Task Force for Nuclear Power[1]

The plutonium breeder reactor is a government financed moloch, plagued by catastrophic dangers, massive cost overruns and questionable economic value, which the government technocrats are building for the private utilities . . . .lemon socialism.

-Ralph Nader[2]

Since its inception controversy has surrounded the development of the Liquid Metal Fast Breeder Reactor (LMFBR) program. Why? The LMFBR presents significantly higher risks than the current generation of conventional Light Water Reactors (LWR), due mainly to the safeguards problems associated with the breeder's plutonium fuel cycle. Plutonium creates hazards to human welfare for several reasons. It is an extremely toxic substance. Furthermore, it is relatively easy to construct a nuclear bomb out of an quantity of plutonium the size of a softball and small amounts of plutonium can be used directly as radiation dispersal weapons. These potential dangers are accentuated by the breeder fuel cycle, which requires large amounts of cross-country transportation of nuclear materials. Shipments in transit are especially vulnerable to theft and sabotaged induced disasters. Nuclear black markets for terrorists and hostile governments may develop.

In the midst of this controversy, the LMFBR has been given the highest priority in recent federal energy expenditures. During fiscal year 1973, out of the total energy research and development budget of 0.7 billion dollars, the breeder received 0.3 billion dollars and "other nuclear" was allocated 0.2 billion dollars.[3] Through 1974, the LMFBR has consumed 1.8 billion dollars, and the Energy Research and Development administration (ERDA) conservatively estimates an additional 8.9 billion dollars, (omitting operating subsidies to early commercial breeders and private capital) will be needed to bring the project to fruition. ERDA hopes the first commercial models will be available in 1987 and "optimistically" projects 186 operative LMFBR's by the year 2000.[4]

Why has the breeder reactor been emphasized? Proponents cite national security, lower long-run energy generation costs, and a somewhat lower thermal pollution capacity. It is true that the breeder technology offers an advantage in meeting a short-term energy independence goal because of the relative scarcity of uranium 235 for the LWR. Dale has shown that "taken by itself, U-235 makes only a minimal contribution to overcoming oil scarcity."[5] Only 0.7 percent of mined uranium is in the U-235 form; most is U-238 which cannot be used in the LWR but can be converted into plutonium 239 for use as LMFBR fuel. In addition, the breeder reactor actually produces more fissile Pu-239 than it consumes. Nevertheless, the relevant questions are whether health and safety standards will be constraining factors and whether solar power, fusion, or alternate nuclear cycles might be more economical alternatives when all the costs are included.

Opponents of the LMFBR have produced counter-

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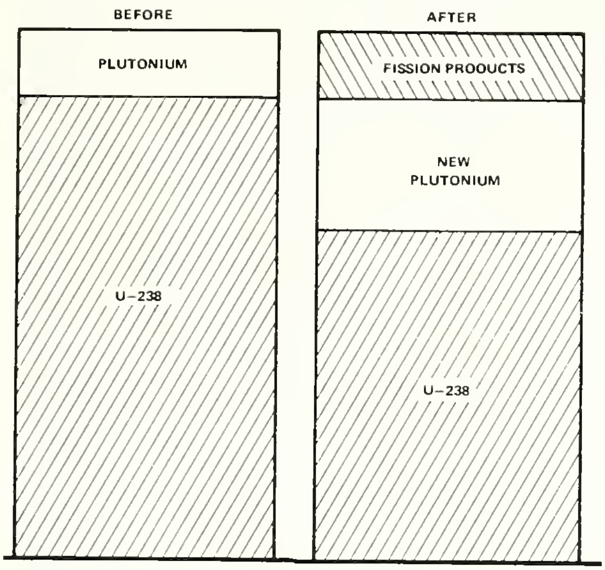


The breeder produces more plutonium than it consumes out of non-fissionable uranium 238.

Source: General Electric, "Our Only Reasonable Alternative"

studies showing the breeder cannot be justified from an economic point of view when more conservative assumptions of future energy demand, uranium supply, the rate of time discount, and the date of commercial introduction are made.[6]

However, the LMFBR does not produce higher levels of routine radiation emissions than conventional reactors, and under ordinary conditions, these levels will be below natural background concentrations. Core Disassembly Accidents are no more likely for the LMFBR than the LWR. There is, though, one area of additional hazard for the LMFBR fuel cycle. A National Science Foundation survey of scientists pinpointed a high degree of concern over nuclear material safeguards. This is where the breeder carries extra risks.[7] Nobel laureates line up on both sides of nuclear power issues. The average citizen is not sufficiently informed.

The purpose of this study is to examine the safeguard risks associated with the breeder reactor. First, the safeguard problem is defined. The safeguard risks of the breeder reactor are compared in relation to the other types of nuclear reactors considered for use in the United States. (These reactors operate on different fuel cycles and safeguard risks depend on the fuel cycle.) This is followed by a discussion of the safeguard risks, and the methods and costs of assembling a safeguards system. The article concludes by emphasizing the conflicting array of opinions and policy implications for the breeder program.

The Safeguards Problem

Safeguard risks are narrowly defined as one subset of nuclear power safety risks. *Safeguard risks are man-made in origin; they include nuclear theft and subsequent use of Strategic Nuclear Material* (SNM) for bombs or radiological dispersal weapons as well as acts of sabotage which may induce accidents in operation or transportation.* ERDA's second environmental impact statement on the breeder program discusses the safeguards issue but does "not attempt to quantify the risk on the rationale that the frequency of such occurrences cannot now be estimated."[8] Uncertainty is large because society is facing a new problem and firm safeguard methods and policies have not yet been established.

Plutonium and Radiation Risks

Even though safeguard risks have not been quantified, they are real, and could prove damaging to human welfare. There are four broad categories of radiation danger: somatic, genetic, teratogenic, and carcinogenic. It must be emphasized that the effect of radiation is cumulative; the total body burden is important.

Somatic effects refer to physical damage to body cells and tissues. The immediate result of exposure of human tissue to radiation is the removal of electrons which are then free to ionize other molecules. Chemical bonds split and cell structures become disorganized. Plutonium 239, the primary fuel used in the LMFBR, is a heavy emitter of alpha particles which cannot pentrate through the skin. Inhalation is the primary mode of contact because most forms of plutonium are relatively insoluble. This does not mean that somatic effects are confined to the respiratory system because the lymphatic and circulatory systems transport the dose throughout the body. Much of the non-lung body burden of plutonium is stored in the skeletal system. Possible results of somatic damage are death, growth impairment, mental retardation, cataracts, and sterilization.

However, the immediate somatic effects of plutonium exposures may be the least important. A dose may have deadly future ramifications to the exposed individual and to future generations. According to Russell, a dose of sixty rads* per generation (30 years) delivered continuously would double the mutation rate.[9] The United Nations Scientific Committee on Effects of Atmospheric Radiation suggests that there is no threshold for genetic effects and "the frequency of mutation is proportional to dose, but is not independent of dose rate."[10] Genes have somatic implications as well. Lederberg, a Nobel laureate in Genetics, writes, "It is generally accepted that there is a genetic component in much, if not all disease."[11]

Radiation is also teratogenic; it has the ability to cause birth defects.

* *Strategic Nuclear Material consists of material that can be fabricated into a fission bomb. A strategic quantity is the amount of material needed for the construction of one bomb. Substrategic quantities of plutonium are also dangerous due to its toxicity.*

***The rad is a dose corresponding to the absorption of one hundred ergs of energy per gram of body tissue.*

A fourth possible result of radiation exposure is carcinogenesis. The exact process of how injury initiates cancer is not known and there are long and variable periods. One ten millionth of an ounce of plutonium injected subcutaneously in dogs produces bone cancer.[12] The National Academy of Sciences Commission on Biological Effects of Ionizing Radiation (BEIR) estimates the lung cancer risk at 1.3×10^{-6} per year-man-rem* for adults.[13]

Gofman and Tamplin take a more extreme view. They claim the cancer risk factor is 1800 times greater than the BEIR estimate. "If the average exposure of the U.S. population were to reach the allowable 0.17 rads per year average, there would, in time, be an excess of 32,000 cases of fatal cancer plus leukemia per year, and this would occur year after year."[14]

Plutonium may also present special dangers. The International Commission on Radiological Protection has warned that, "In terms of amount available, projected usage, extent of anticipated accidental human exposure and radiotoxicity, plutonium is the most formidable radionuclide in the periodic table."[15]

"Terrorists frequently attack their single-minded goals with fanaticism and ruthlessness."

Plutonium burns spontaneously when exposed to air, forming intense insoluble plutonium dioxide particles. One ounce of plutonium can yield 10 trillion small aerosols which may be suspended in the atmosphere. Some scientists have reported that plutonium emits a special type of alpha particle known as a "hot particle" because of its intensity and small size. These small radioactive aerosols may penetrate deeper into air sacs and remain embedded in respiratory tissues. It has also been suggested that "Energy dissipated in a limited volume may be far more carcinogenic than if the same type of radiation were to dissipate its energy over a much larger mass."[16] According to Geesaman, plutonium "hot particles" pose a carcinogenic risk between 100 and 10,000 times greater than the National Commission on Radiological Protection (NCRP) calculation. The British Medical Research Council and the U.S. NCRP have rejected the "hot particle" hypothesis as unfounded. ERDA has not taken a formal stand on the matter, awaiting the results of a study to be completed in 1985. Hardly anything is known about the total long-run effects of radiation in the biosphere.

Nuclear Terrorism and Theft

Radiation could be released from a variety of terrorist activities following a theft of nuclear materials. Terrorists frequently attack their single-minded goals with fanaticism and ruthlessness. Westinghouse Corporation "clearly recognizes that the threat of exposure, hijacking, and theft increases as more light water and breeder reactors are placed in service." However, Westinghouse does not appreciate the nature of a terrorist when it claims that "spent fuel has too high a level of penetrating radiation to be a target of theft or diversion."[17] Terrorists have been known to take health risks and often wish to die as martyrs to their cause. Hostile governments may also be a threat.

What are the risks of nuclear theft? Opinion varies. The impact statement prepared by ERDA states that "to obtain significant quantities, a large number of thefts must be committed with a concomitant high risk of detection."[18] Former Congressman Hosmer, a nuclear power advocate and ally of the Atomic Energy Commission (AEC), warns that, "Liberating a half gram of plutonium at a time might be so small an amount as to be relatively undetectable even by the best black boxes and the sharpest eyed inspectors."[19]

Where is nuclear theft most likely to occur? Fresh fuel assemblies are prime targets because they contain SNM in large quantities and are pre-packaged for safe handling. Also, there are fewer physical barriers to cross in transit than at a nuclear facility. Willrich and Taylor downgrade the possibility of plutonium theft in stages when it is mixed with intensely gamma radioactive products. The most susceptible areas are then

> . . . the output of reprocessing plants, plutonium storage facilities, fuel fabrication plants, fresh fuel storage facilities, and the transportation links . . . Among these the places that would be most vulnerable to attempted thefts would be the plutonium load-out rooms at reprocessing plants where an employee might pour out very small quantities of plutonium nitrate into a container for surreptitious removal; or at fuel fabrication plants, where an employee might steal a few fuel pellets or a plutonium-bearing fuel rod or fuel pin.[20]

What will happen to stolen plutonium? Employee-related thefts will probably enter a black market since employees with clearances are rarely members of subversive organizations. Hijacked-transportation-related thefts are probably placed directly in the hands of terrorists or organized crime. The profit potential is tremendous. Plutonium is valuable as a legitimate fuel source. One kilogram "can produce as much energy in a power station as 1,700 tonnes** of oil."[21] Its black market value will be much higher as

**The estimated biological effect of a radiation dose is measured by the rem. For example, a dose of 0.1 rad from neutrons or high energy protons is approximately equal to one rem. One rem is also equivalent, roughly, to one rad of X-Ray or beta radiation and a mere 0.05 rad from particles heavier than protons.*

***One metric tonne equals 1000 kilograms or 2200 pounds.*

an instrument of death and destruction capable of bringing about land conquest, religious, racial, or national genocide, coups d'état, and international income redistribution. In 1970, a fourteen year-old honor student in Orlando, Florida bluffed a nuclear bomb threat and almost succeeded in gaining one million dollars of ransom money.

Taylor, in congressional testimony, insisted that present safeguards are "not adequate to prevent theft by heavily armed groups with resources and motivation comparable to the Brinks gang and other groups of professional criminals".[22]

Three Nuclear Fuel Cycles

In order to evaluate the likelihood and places of origin of potential safeguard risks in the breeder reactor, an examination of its nuclear fuel cycle is crucial. Determining the relative risks involved requires a comparison with the two other major types of nuclear reactors. The three types of fission reactors considered serious contenders in the upcoming U.S. energy picture are the Liquid Metal Fast Breeder Reactor (LMFBR), the conventional Light Water Reactor (LWR), and the High Temperature Gas Reactor (HTGR). Each operates on a different nuclear fuel system.

The LMFBR* releases energy as it converts uranium 238 to plutonium 239. Occasionally, Pu-239 captures an extra neutron without undergoing fission. The product, plutonium 240 poisons chain reactions in the reactor. Therefore, when the 240 isotope content builds up to 10 percent to 20 percent of the total plutonium content, the fuel rods have to be removed. At that time, there is also more Pu-239 than existed originally in the fuel assembly. Economic factors encourage separation of the Pu-239 from the Pu-240 and subsequent reprocessing for re-use as fuel for either the LMFBR or the LWR. After reprocessing, the material is then transported to a fuel fabrication plant. From there, it is ready to be sent to a reactor.

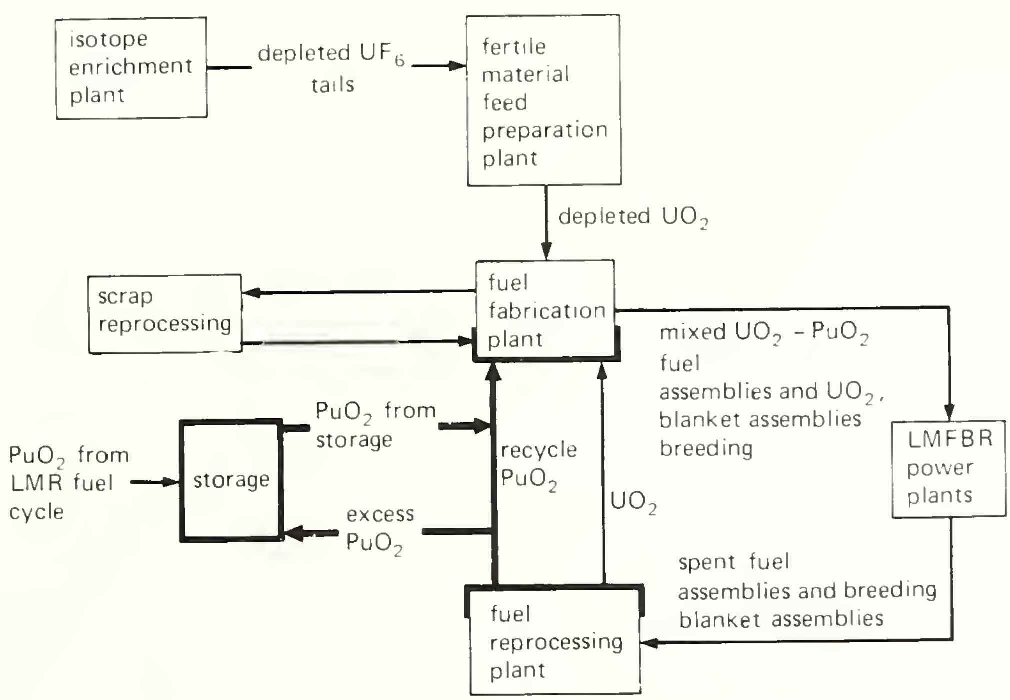
Plutonium 239 poses most of the safeguard problems because it can be used to construct a nuclear bomb. The 240 isotope is useless to potential bomb makers. However, both isotopes are strong alpha emitters and can be used in radiological dispersal weapons. Large quantities of plutonium 239 are available in forms relatively safe to handle after reprocessing up until the new fuel rods are inserted into a reactor core. Spent fuel rods** are less of a problem since detection and recovery is simplified. (The gamma radioactive fission products can be more easily identified by Geiger counters.) The size of the nuclear material flows is indicated by the example of the Clinch River Breeder Reactor. This small government demonstration LMFBR located in Oak Ridge, Tennessee will require 20 tons of plutonium and 210 tons of uranium during its 30-year plant life. One third of the fuel core will be replaced annually.[23]

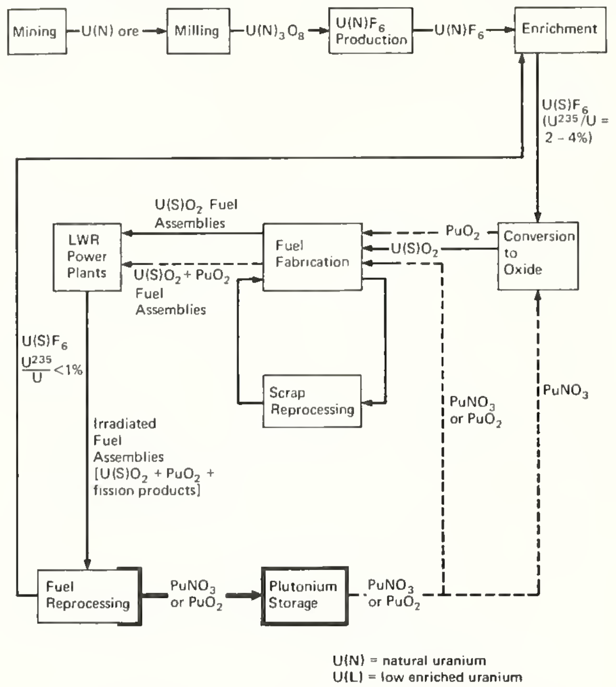
The current generation of nuclear power plants, the LWR, splits uranium 235. During the process, some plutonium is produced as a by-product. Since it is possible for an LWR to operate on recycled plutonium when certain modifications in plant design are made, spent LWR fuel may also be shipped across country to

**The term "liquid metal" refers to the sodium coolant in the breeder reactor; the nuclear material is in the solid form.*

***Spent fuel is the depleted nuclear material left over after fission.*

The Liquid Metal Fast Breeder Reactor (LMFBR) Fuel Cycle





The Light Water Reactor (LWR) Fuel Cycle

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capital-intensive reprocessing facilities.* The magnitude of safeguard risks is much lower in the LWR than in the LMFBR for several reasons. First, *the LMFBR involves approximately six times as much plutonium overall and two to three times as much in fresh fuel assemblies, when compared to the LWR with plutonium recycling.*[24] Second, LWR fuel rods are much less concentrated than the LMFBR rods. A thief would need only 50 to 100 kilograms of rods to be able to build a bomb from LMFBR fuel rods at this stage.[25] The uranium in LWR fuel requires extensive processing before it can be used in a bomb and much more material must be stolen to acquire enough plutonium for a bomb.

The third major nuclear reactor type, the HTGR, converts relatively abundant thorium 232 to uranium 233. Like the LWR, the HTGR is not a breeder, although the HTGR has a higher efficiency and may be a partial solution to the problem of U-235 scarcity. After fabrication into fuel particles, the HTGR fuel is relatively dilute and large amounts of nuclear materials are transported in this fuel cycle and shipments appear especially vulnerable.

**The first reprocessing facility ceased operation in 1974 with the intention of resumption after enlargement of the West Valley, New York plant. Plutonium has been stockpiled at the facility. Recently, the plant was abandoned by the parent company leaving the plutonium disposal problem in the hands of the State or Federal government. At the present time, there is no LWR plutonium recycling operation in the United States, but another facility is planned in Illinois.*

In assessing the safeguard ramifications of these three nuclear fuel cycles, Willrich and Taylor have developed scenarios relating annual production rates for strategic nuclear materials to nine combinations of reactor types in use. Quantities are highest when the breeder is the predominant reactor and LWR plutonium is recycled. Potential bomb equivalents range from a low of 7,000 annually in 1980 to a year 2000 high of 250,000. The estimated number of plutonium truckloads to fuel fabrication plants varies from 300 to 3000 annually depending on the amount of plutonium recycling in the scenario. For all cases, Willrich and Taylor project 1000 American nuclear reactors, five to fifteen uranium enrichment plants, twenty fuel fabrication plants, and twenty fuel reprocessing plants in the year 2000.[26]

Cochran estimates that 100 million kilograms of plutonium will be in use by the year 2000.[27] He assumes a hypothetical figure of plutonium residuals to the environment from all sources including core accidents, nuclear theft, transportation losses, and natural disasters at a millionth of the stock in use. Placing the cancer risk at 0.05 per person per microcurie of plutonium 239 inhaled, Cochran estimates that 10^8 cancers would result. He admits that his estimate may be high or low by a factor of one thousand since the biosphere may provide a sink for some plutonium, but food chain cycling may countervail the effect.[27]

Types of Safeguard Problems

Once nuclear material has been stolen, there are three basic types of potential safeguard problems: the construction of nuclear bombs, radiation dispersal weapons, and the sabotage of nuclear facilities and transportation shipments.

One of the frequently mentioned complications of nuclear theft is the highly emotional issue of illicit nuclear bombs. Can a bomb be constructed from stolen SNM? How does the relative difficulty of fabrication compare for the LMFBR and alternate fuel cycles? How much material must be stolen to build an explosive? Not surprisingly, these questions have not been resolved.

Conflicting opinions abound. ERDA maintains, "While it does not theoretically take extremely large quantities of plutonium to manufacture a nuclear explosive, the process is not an easy or sure one to accomplish. The possibility of harm to the weapon maker is high, as is the possibility that the potential weapon would detonate prematurely with very minor results."[28]

Terrorists are interested in crude fission bombs, and therefore do not need to construct efficient, lightweight missile warheads. Taylor suggests that one person working alone could design and build a bomb equivalent to 100 tons of explosives from ten kilograms of reactor grade plutonium oxide. Such a bomb could kill 100,000 people in an urbanized area.[29] According to Kinderman, "the equipment requirements would not be large . . . a few tens of thousands of dollars of equipment properly installed."[30]

Terrorist groups able to accumulate strategic quantities of plutonium but lacking explosive fabrication expertise could conceivably kidnap or bribe someone to help them. Classified information and underground handbooks on bomb construction are already reputedly in circulation.

How risky is bomb fabrication to the terrorist? Because of the toxicity of plutonium, it would be wise to work with it behind an air-tight barrier to prevent inhalation. Heavy shielding is not necessary because most of the emissions are non-penetrating alpha particles. A bomb maker working with U-233 stolen from an HTGR fuel cycle facility would face larger health risks from penetrating gamma rays.

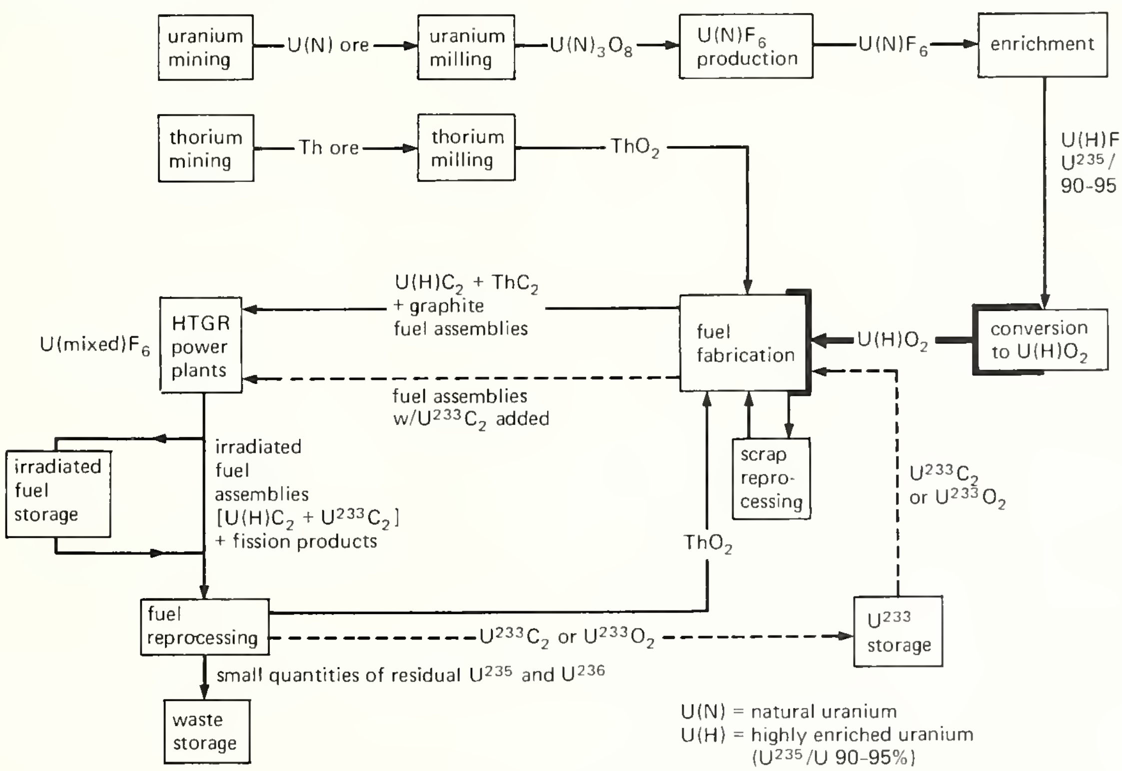
How much nuclear material is needed to build a bomb? One kilogram of plutonium 239 will not explode. A few neutrons will be undergoing fission, but they will generally escape the surface of the material without initiating further fissions. The amount of SNM that must be present for explosive fission is called the critical mass. It is sixteen kilograms for plutonium 239 (delta phase) and fifty kilograms for U-235.[31] Reflective metals such as beryllium can reduce the required critical mass substantially.

Plutonium will be present in many different forms in the various stages of the LMFBR cycle. Metallic plutonium is best for bomb-making. The Nuclear Regulatory Commission (NRC) has issued guidelines that in-transit plutonium should be in the oxide form to minimize damage in case of a transportation accident. The oxide form requires no special processing before use in a bomb core, but conversion to the pure metal increases the efficiency of a bomb and is not difficult. When plutonium is produced from U-238 in a breeder or conventional reactor, it is reprocessed into the nitrate form. Plutonium nitrate fissions too slowly to be directly usable in a bomb; however, it is a simple matter to transform it into the oxide form.

Spent breeder fuel assemblies contain relatively large proportions of plutonium 240. If the 240 isotope content is too high, the bomb may not fission or it may predetonate, fizzling out without suddenly releasing large amounts of radiation and energy. Yet, technology is now being developed to separate Pu-240 more easily.

In contrast, LWR fuel is enriched to only two or five percent U-235 and it is not directly usable in a nuclear bomb. U-238, the bulk of LWR fuel, will not sustain a chain reaction in a bomb. Currently, the technology for uranium enrichment is classified and complex. The processes require huge amounts of electricity and extensive facilities. Technology is in a constant state of change and research is being done on a laser method of uranium enrichment.

Another possible alternative, the HTGR, is susceptible to nuclear theft for bomb construction purposes at only two stages in its fuel cycle; during oxide con-



The High Temperature Gas Reactor (HTGR) Cycle

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version and fuel fabrication.

At the oxide conversion step, a thief would have to accumulate "125 kilograms of material to have enough uranium, after separation from the thorium, for a crude fission bomb."[32]

At fuel fabrication, HTGR uranium is enriched to 90-95 percent U-235. Despite the high enrichment level, once this material has been fabricated into fuel particles, it is not optimal bomb material. The U-235 is considerably diluted by thorium; requiring extensive chemical separation the HTGR fuel particle coatings also impede exploitation. The graphite must be burned off; silicon carbide will not burn and is not acid soluble. It must be crushed between rollers. A nuclear theft of four tonnes of HTGR fuel would provide fifteen kilograms of usable high enriched uranium. Before graphite coating and thorium combination, a thief would still need 1500 kilograms of particles.[33]

Radiation Dispersal Weapons

Stolen nuclear material, especially plutonium, can be very useful to terrorists lacking sufficient quantities for bomb construction. Plutonium could be scattered in the wind in populous areas, thrown into the water supply, or spread through buildings. Dispersal would claim a heavy toll in human life, property damage, and land contamination. A timing device could be used to release finely divided radioactive particles from containment.

Decontamination costs would run in the millions of dollars for a skyscraper. Outdoors, plutonium would be diluted by fresh ambient air and swept away by turbulence. However, it would be harder to contain the pollutant, and environmental damage may be more persistent outside. After settling on the ground, particles may re-enter the air or leach through the soil to ground water. For rational or irrational reasons, society may shun places victimized by radiological dispersal, incurring opportunity costs. Microgram quantities of plutonium could be placed in seemingly empty envelopes and mailed as inhalation letter bombs. Inhalation of uranium is relatively less harmful. "Plutonium 239 in equilibrium with its daughters has a direct radiological hazard about 10,000 time that of natural uranium in equilibrium."[34] Still larger quantities of the U-233 isotope product of HTGR's would be needed to match the dispersal hazard potential of plutonium.

The environmental impact statement on the LMFBR discounts the danger of radiological weapons, terming their use possible, but speculative. "Although the potential consequences could be significant, they would not approach the severity of a nuclear explosive. The use of radiological weapons does not appear to be consistent with the observed behavior of terrorists or extortionists."[35]

In fact, although not quite as dramatic as a nuclear bomb, radiological dispersal may have as much emotional impact. Foreign nations are probably less interested in radiological weapons because they can be self-defeating if the desired objective is conquest of agricultural land or special resources. Purely political or ideological wars can be fought with dispersal weapons, but many other biological warfare toxins are available and easier to use.

Nuclear Sabotage

Nuclear terrorism can take place without nuclear theft. Sabotage is derived from the French word *sabot* meaning a wooden shoe. A *sabot* strategically inserted in factory machinery very effectively gums up the works. Successful nuclear sabotage is far more worrisome. Armed groups could take over a reactor and cause a deliberate malfunction. A sabotage-induced incident would entail expensive repairs during a long shut-down period with additional costs in foregone output. Although the accidental Brown's Ferry reactor fire was not a safeguards-related event, it demonstrates the size of possible losses. Economic cost exceeded £50,000,000 (one British pound is approximately equal to 1.6 American dollars).[36]

During a LMFBR core accident, released energy may cause the liquid metal (sodium) coolant to boil.

"Plutonium could be scattered in the wind in populous areas, thrown into the water supply, or spread through buildings."

Normally, sodium lowers the temperature, decreasing the fission rate. Boiling sodium bubbles leave voids or areas of open space where heat and neutrons are not absorbed. This *positive sodium void coefficient* propagates the uncontrolled chain reaction. Released energy can further vaporize sodium, cause melting and relocation of the cladding and fuel core, and break apart mechanical reactor features. Webb estimated that because of runaway reactivity, a nuclear reactor explosion may be equivalent to as much as 20,000 pounds of TNT.[37]

Ralph Nader disputes ERDA's Rasmussen report findings on accident results. He quotes the American Physicist Society's projection that, "A reactor accident would cause 10,000 to 20,000 deaths, 22,000 to 350,000 injuries, 3,000 to 20,000 genetic deaths, plus widespread and enduring land contamination."[38]

Willrich and Taylor are less pessimistic on the sabotage issue because reactor safety designs are inteded to minimize susceptibility to natural and manmade disasters and to contain any accidents that might occur. They conclude that bombing a reactor core to destruction would be less dangerous than constructing a low yield fission bomb.

Transportation and the Safeguard Issue

Transportation may be the most vulnerable link in the chain of safeguards. Scenarios dependent on the LMFBR, or to a lesser extent the LWR with plutonium recycle, mandate the shipment of large amounts of strategic nuclear material. Projected data on the number of shipments and their contents is available for the Clinch River prototype breeder. There will be 84 to 106 annual shipments directly attributable to this single reactor operating at sub-commercial levels. 1250 kilograms of plutonium oxide, enough for 100 fission bombs will be shipped each year from the Clinch River prototype. NRC estimates shipping distances at from 500-1000 miles.[39] ERDA's risk determination for transportation in the LMFBR impact statement was based solely on assumptions and judgment. The EPA was unable to conclude that existing transport cask designs are adequate under actual accident conditions. ERDA made no attempt to predict risk from theft or sabotage of shipments.

The Nuclear Regulatory Commission has no jurisdiction over common carriers to avoid entering the domain of the Department of Transportation and the Interstate Commerce Commission. NRC can only directly set standards for nuclear facilities. It would be difficult to require secruity clearance for employees of common carriers.

Truck shipments are the most susceptible to diversion of SNM. Trucks are allowed to carry non-nuclear cargo along with SNM shipments, provided that no extra stops are made before discharging the nuclear cargo. Trucks should be monitored closely to insure adherence to the planned route.

Railroad cars are more difficult to hijack. On the other hand, no special design requirements pertain to trains and there are no restriction on stops and storage methods. It is difficult to plan ahead against theft conspiracy by railroad employees.

As for air transport, we must be prepared to prevent skyjacking and theft by employees or agents disguised as employees. There are currently no special regulations for the physical protection of air shipments or for guard-escorts. The Institute of Nuclear Materials Management notes, "The inability of the air industry to properly handle the cargo handed to it for air carriage now approaches a national scandal."[40] Air shipments are often combined with trucking of SNM from the airport to the destination.

"Transportation may be the most vulnerable link in the chain of safeguards."

Places of transfer or mode changes as well as warehouses must be carefully safeguarded. So far, there have been 300 reported accidents in transportation of radioactive materials. NRC claims no deaths or injuries resulted. "Accidents" can also be made to occur deliberately by intentional destruction of mechanical parts. A terrorist could also attack or bombard a shipment of nuclear materials. Transportation modes do not have the sophisticated design containment devices and barriers which help protect nuclear facilities. Although the quantity of SNM at stake is smaller, for a given shipment, the amounts are not strategically insignificant. The AEC projected 9,500 *spent fuel* shipments in the year 2000, with a mean distance of 500 miles or a total of 4,750,000 vehicle-miles. Fifty percent of these would be from LMFBR fuel cycle needs. Weinberg's counter-estimate is 12,000,000 vehicle miles traveled.[41] Nuclear shipments by any mode should be protected by armed, trained guards. Travel routes and speed should be carefully observed and back up force available.

What are the effects of a transportation "accident"? NRC's estimates are based on their expectation that the fuel cladding on unirradiated fuel assemblies will remain intact should the inner and outer containers be breached. Even a small break in the inner container could cause coolant loss spilling the entire contents of fuel rods as further breaks open up. NRC admits the severity of such an event, but considers the probability "incredible".

Safeguard Lapses

Industrial and governmental advocates of the LMFBR program who cite the generally good safety record of the nuclear industry in the past are naively attempting to justify extrapolations into the future. Nuclear power is becoming de-mystified as knowledge about its capabilities and limitations becomes more widespread. In a future predicated on a plutonium fuel cycle, vastly increased amounts of this element not found naturally on earth will be circulating across the country. Criminals and terrorists will gain awareness of their opportunities to take advantage of new technology.

Overall, the past record of the nuclear industry has been satisfactory. Nevertheless, there have been a number of serious lapses in nuclear safeguards. Most have not been given wide publicity. Edward Teller commented, "So far we have been extremely lucky. But with the spread of industrialization, with the greater number of simians monkeying around with things they do not completely understand, sooner or later a fool will prove greater than the proof even in a foolproof system."[42]

Carl Walske, former Assistant Defense Secretary for Atomic Energy Matters in 1974 Congressional testimony, stated that, "3600 employees with access to nuclear weapons or materials were replaced in one year because of alcoholism, mental illness, drug abuse, and disciplinary problems."[43]

Can the human element ever be eliminated as a risk factor? A serious lapse in safeguards occurred at the Kerr-McGee fuel production plant in Oklahoma. Large quantities of plutonium were reported missing and one employee, Karen Silkwood, died under mysterious circumstances. The Nuclear Energy Liability-Property Insurance Association is one of two pools underwriting nuclear policies. It has made 30 claim payments since 1957. None of these accidents occurred at power plants; most were transportation-related. The incidents include a $300,000 settlement to the estate of a cancer victim who was contaminated by plutonium at a truck terminal in 1963 and the 1975 loss of contaminated reactor filters after the boxes fell off a truck. The filters later turned up in a police "lost and found".

Safeguard Methods

There are four main purposes of a safeguards program: 1) to prevent diversion of nuclear material, 2) to detect deversion after its occurrence, 3) to recover lost material safely, and 4) in the event of a failure in the first three objectives to establish a scenario for protection of human welfare and minimization of environmental damage.

The Federal government and the nuclear power industry should work together with the scientific community and the public to develop a comprehensive safeguard system. Federal authority is currently fractionated. EPA urges a more clear-cut delineation of responsibility between ERDA and NRC. The AEC admitted in 1974, "Almost no standards exist in the materials protection area and in many cases the basic data needed to develop such standards have not been developed."[44]

We are now spending less than 10,000,000 dollars a year on safeguards. Hardly any research has been done in the area of stolen material recovery. ERDA is conducting a threat definition study to examine the uses of stolen nuclear material and the characteristics of possible perpetrators. The study should be complete in 1978. ERDA is also funding a small amount of research in computerized material monitoring. The agency will make a decision on the safeguards-acceptability of commercial LMFBR's in the early 1980's.

What are some of the methods used in a safeguard system? Strategic Nuclear Material accountancy is supposed to show if safeguards are working properly. It cannot prevent nuclear theft, but in the ideal case it serves as a deterrent by increasing the possibility of apprehending the culprit and capturing the material. In reality, there is a long time lag between theft and discovery. The acceptable limit of error in measurement for SNM at a reprocessing plant will represent a large amount of unaccounted for material. There is also a large amount of material located in the inaccessible parts of machinery and reactor cores. Edward Teller is concerned, *"I don't think anybody can foresee where one or two or five percent of the plutonium will find itself."*[45] The nuclear industry hopes for some improvements in on-line nondestructive assay techniques so that lag times can be reduced.

Many measures serving as safeguards are designed for routine physical protection. These safety methods include radiation shielding, containment to prevent criticality and allow heat dissipation, entry and exit controls, storage vaults, and foundations and barriers designed for maintaining stability in the event of earthquakes and other natural phenomena.

Other measures have been developed for security purposes. Security plans are not available to the public for obvious reasons. The development of portal radiation monitors and conventional explosive monitors could greatly improve a safeguard system. An alarm system could be coordinated with mechanized physical barriers and could alert the security force. A security force in conjunction with the rest of a safeguard system should be designed to control the "maximum credible" set of adverse circumstances. The question of government versus private responsibility for safeguard controls and costs has not been settled. ERDA is studying the possibility of a Federal nuclear guard force.

Alvin Weinberg urges creation of a "nuclear priesthood", a technocratic elite, which may be governmental or private, dedicated to the maintenance of security. Ordinary police forces may not appreciate the danger or may be unable to cope with system complexities. A "nuclear priesthood" may have some undesirable consequences. The FEA warns that, *"There should be consideration of the impacts on society . . . since safeguarding against plutonium theft is basically an insoluble problem without putting the whole nuclear energy system under military controls."*[46]

Britain's Royal Commission on Environmental Pollution warns that the "use of informers, infiltrators, wiretapping, checking on bank accounts, and the opening of mail . . . are highly likely and indeed inevitable" in an LMFBR economy.[47]

Finally, if society were willing to pay the price of possible loss of democratic values, how effective would the safeguard system be? According to Willrich and Taylor, "The quality of effort would be well beyond what the public normally expects from the law enforcement authorities in crime prevention, or even in the theft of large amounts of money."[48] Some serious lapses will undoubtedly occur.

Changes in fuel composition also have a large bearing on nuclear safeguards. The "cooldown" method is a way to change the composition of spent nuclear fuel without altering the fuel input. The LMFBR burns fuel at high specific power* favoring the formation of intense, short-lived radionuclides. For this reason, dispersal of spent LMFBR fuel carries a larger danger. Certain of these radioactive elements with high biological potentials decay to significantly lower concentrations with the passage of time. Weinberg suggests cooldown for a 360 day period before shipment to cut heat generated in shipping casks of spent fuel by a factor of six. By comparison, ERDA cost calculations in the environmental statement are based on a 30 day cooldown period. Cooldown is costly; it decreases the plutonium doubling time. It has been estimated that there is a loss of usable radioactive material of eighteen dollars per kilogram per month of waiting time.[49] That does not include additional costs associated with storage and inventory.

It is also possible to increase the danger to nuclear thieves by adding gamma emitters to fresh or spent fuel. Unfortunately, that may backfire and increase

* *Specific Power equals watts per pound.*

the risks to the public. ERDA is also studying the possibility of poisoning unauthorized fissioning by the addition of isotopes which make it more difficult to construct bombs with large explosive potentials. Alternately, the chemical or physical forms might be altered to reduce toxicity in the event of dispersal. The most drastic fuel changes would be to reject the LMFBR fuel cycle and to avoid LWR plutonium recycle despite the economic incentives.

Safeguard risks may also be reduced by siting techniques. For example, co-location of some or all stages of fuel cycle facilities is recommended by EPA as a way to "greatly reduce the risk that a nuclear shipment between two facilities might be hijacked and also results in substantial savings in transportation costs to the enterprise."[50] A clustering of facilities into nuclear "parks", would also concentrate the problems of thermal pollution and susceptibility to natural and man-made disasters. Colocation is expensive in terms of foregone economies of scale since there would be a larger number of smaller fuel cycle facilities. Teller suggests location of reactors and facilities underground or underwater.

The Costs of Safeguards

Fortunately, the costs of pre-planned safeguards may not be unreasonable. Willrich and Taylor, critics of the meager controls originally anticipated, are optimistic. "It may appear . . . that the development and application of a system of safeguards that will keep the risks of nuclear theft very low indeed will result in enormous costs . . . this is not the case for a safeguard system which employs the best available technology and institutional mechanisms."[51]

Spokesmen from ERDA, NRC, the Joint Congressional Economics Committee, Westinghouse, and General Electric concur that the marginal cost of preplanned safeguards will be small relative to nuclear power expenditures, on the order of 1 percent to 2 percent of total nuclear costs. The exact magnitude is a matter of guesswork until firm regulations and requirments are set.

Because people are not currently aware of the magnitude of the problem, the political centers of power are not moving very quickly on the safeguard issue. In a 1976 report, the Government Accounting Office (GAO) found many safeguard deficiencies at ERDA contractor facilities and pointed out the need for "additional guards, alarms, doorway detectors, night vision devices, and improved communication equipment." But Congress appropriated less than half of the administration's 1976 request to upgrade contractor safeguards. ERDA has been allocated only 2.1 million dollars in fiscal 1976 to improve instruments measuring nuclear material.[52]

Conclusions

The safeguards issue is by no means resolved. Many questions are still unanswered. The probability of safeguard circumvention is very real, although as yet undertermined, due to uncertainty and the inchoate nature of safeguard planning. Various groups and individuals have expressed their own opinions about safeguard feasibility and the proper course of action for the Liquid Metal Fast Breeder Reactor program.

EPA was unable to conclude "on the basis of the information presented in the PFES* that commercial development of the LMFBR program can be accomplished without causing future unacceptable environmental impacts."[53]

The Scientist's Institute for Public Information denigrates the role of future technological improvements, "The advance of knowledge does not necessarily show the risks of LMFBR's to be smaller than ignorance or prudence would have thought them."[54]

The Rand Corporation concludes that due to the large amount of uncertainty surrounding the program, the LMFBR should be developed in an "austere, incremental sequential" manner, "with adequate time for testing and evaluation."[55]

A number of observers urge greater flexibility in an energy program to avoid excessive dependence on any single generation method. Edward Teller allows for the possibility that the "LMFBR will become the most useful reactor," but he stipulates that, "Claims to the effect that sooner or later the LMFBR will become unavoidable are unproven."[56] *The Royal Commission on Environmental Pollution urged postponement of the plutonium fuel economy for as long as possible while other alternatives are being developed.* Willrich and Taylor are concerned, yet more optimistic, "Obviously, there is no perfect solution to the problem of nuclear theft any more than there is a final solution to the problem of crime. But there are safeguards which if implemented, will reduce the risk . . . to a very low level, a level which, in our opinion, is acceptable."[57]

What should be done? Decision criteria and assumptions should be chosen conservatively because of the magnitude of potential risks and the lack of scientific consensus. Impartial research should be stepped up and public participation and debate should be encouraged. The Nuclear Regulatory Commission has two major efforts underway, a "Special Safeguards Study" on requirements and a report on the possible creation of a quasi-autonomous agency within NRC, the "Security Agency Study". ERDA is concentrating on threat definition and experimentation and demonstration of safeguard procedures.

These studies will not be complete until 1980-1982. It would therefore be reasonable for the government to hold down LMFBR operational development funds until these other issues are resolved. At any rate, some action should be taken now. Answers cannot be pushed off into the vague future: planning is preferable to procrastination.

Critics hope that ERDA will be able to live up to its promise that the "safeguards program will be designed to attain a level of protection to the public which

**Proposed Final Environmental Statement* would not increase significantly the overall risk of death, injury, or property damage from causes beyond the control of the individual."[58]

Likewise, it would be a futile self-fulfilling prophecy if other energy forms do not become feasible simply because the lion's share of research and development are channelled to the LMFBR, locking us into a single technology.

The plutonium safeguards problem has received little public attention. Few people are even aware of what an LMFBR is. Because this is an important public policy issue, the social decisions should be made by an informed populace.

Footnotes

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