Plutonium 85

The Links Between Nuclear Power, Nuclear Waste, Plutonium
and the Spread of the Bomb

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Preface

Plutonium Now

The nuclear reactor was invented to produce plutonium. All other applications of nuclear reactors came later. The first reactors were built to study the "chain reaction" in uranium, and to use the neutrons from the chain reaction to convert uranium into plutonium for use in atomic bombs. The heat also released was at the outset more of a problem than an asset. In 1985, the position is reversed. The heat from chain reactions is powering hundreds of electric generating sets in nuclear plants in many countries. But the chain reactions are also producing plutonium - some 40 tonnes of it per year worldwide, enough for at least 4,000 atomic bombs.

For more than three decades official nuclear policies have proclaimed that this "civil" plutonium is itself a valuable fuel, a bonus to be credited to the nuclear power plants. Skeptics have long questioned this claim. Now, in 1985, it has become patently indefensible. Plutonium-fueled electricity has proved to be both prohibitively expensive and unnecessary. But the plutonium is still pouring out of the power stations. What is to become of it? What is to become of the long-standing official nuclear policies centered on the production and use of plutonium-fueled systems for electric power? What, above all, is to become of plutonium research and development in those countries that may be more interested in using plutonium for its original purpose - atomic bombs?

Plutonium 85 begins by surveying the world nuclear power scene in 1985 and how it may evolve, weighing the putative role of plutonium fuel for civil electricity generation, in conventional nuclear plants and in so-called "fast breeders." The report then considers the key technology of "reprocessing": chemical separation of the used "spent" fuel from a nuclear power station, to recover plutonium from it. Chapter 3 describes how reprocessing for military purposes has proved to have little in common with reprocessing of modern civil fuel. Civil reprocessing is so technically demanding, and accordingly so expensive, that electrical utilities are fast losing interest in it. Instead, as Chapter 4 discusses, utilities are moving to a range of alternative options for managing their spent fuel.

Chapter 5 shows how the vexed question of disposal of radioactive waste is dramatically complicated by reprocessing, the single nuclear activity that creates more varieties of awkward waste than all other nuclear processes put together. Chapter 6 analyzes the political and diplomatic implications of separating plutonium for ostensibly "civil" purposes. It describes the ambiguous activities and policies of the existing nuclear weapons countries, and indicates the dangerous implications of such ambiguity. If today's weapons-states persist in "civilitary" nuclear operations - using nominally "civil" installations for weapons-production - why should other countries not do likewise? Three nuclear weapons states - the United States, the Soviet Union and the United Kingdom - are depository countries for the Non-Proliferation Treaty. But the example set by these three countries, of blurring the already indistinct borderline between civil and military nuclear activities, is gravely undermining an already fragile Treaty. Nowhere is this more apparent than in the stubborn insistence on pursuing plutonium technologies that make no economic sense in a "civil" context, but that may serve ideally as a cover for weapons-development.

The closing Chapter of this report summarizes the conclusions that can be drawn about plutonium in 1985. It also makes recommendations for changes in official nuclear and plutonium policies in national and international contexts. On past performance, where plutonium is concerned, governments and their powerful nuclear manipulators will not readily yield to the force of rational argument. But an informed general public can provide a potent counterbalance to the entrenched interests of the plutonium people. This report is thus addressed not only to those who make the nuclear policy decisions, but also to those whose future the decisions will determine - the global public.

Chapter One

Nuclear Power and Weapons

In December 1976, Leonard Ross wrote this for the *New York Times Magazine*:

"The bomb is back. Not the hydrogen bomb of the 1950s, which could turn islands into firmament, or the tactical nuclear weapon of the 1960s, which fell out of favor when it couldn't be used on a Vietcong platoon. The atomic bomb in today's news is a very old-fashioned model, made with a few pounds of plutonium and engineering techniques nearly three decades old. It might be no more devastating than the "Little Boy" canister that killed 100,000 in Hiroshima and left an equal number to die of burns and radiation sickness. The only thing new about this kind of bomb is who could get it, and how.

" Who: By 1985, Egypt, Pakistan, South Korea, Taiwan, Brazil, Argentina, Spain, and perhaps 30 other countries.

" How: From the spent fuel of civilian nuclear power plants - plants now being sold all over the world, in ferocious commercial competition, chiefly by the United States, France, and West Germany."

At the time of this writing - May 1985 - an obvious question is "'Why?" Nearly forty years ago, in the 1946 Acheson-Lilienthal report, US atomic pioneer Robert Oppenheimer and his scientific and diplomatic colleagues declared that "the development of atomic energy for peaceful purposes and the development of atomic energy for weapons are in much of their course interchangeable and interdependent . . . The reasons supporting this conclusion are not merely technical, but primarily the inseparable political, social and organizational problem involved in enforcing agreements between nations each free to develop atomic energy but only pledged not to use it for bombs. National rivalries in the development of atomic energy readily convertible to destructive purposes are the heart of the difficulty . . . . No system of inspection . . . could afford any reasonable security against the diversion of such materials for the purposes of war." The authors recommended international ownership of all dangerous nuclear facilities.

History took a different road. The Soviet Union rejected the Acheson-Lilienthal plan as a means of perpetuating an American monopoly on nuclear weapons. The ensuing Cold War led to a policy of safeguarding nuclear knowledge through secrecy, even to the point that the US cut off all scientific collaboration with its wartime allies. But the first Soviet nuclear test, signs of commercial nuclear conpetition between France, Britain, the US and Canada, and scientific impatience with secrecy broke the barricades. In place of secrecy came the euphoria and wishful slogans of "atoms for peace" serving humankind. Here guilt over nuclear weapons could be absolved in grandiose projections for nuclear energy, aid to developing nations, and export earnings. National security took a back seat.

In the driver's seat was a universal belief in the inevitability of nuclear power. It persisted from the mid-1950s through the mid-1970s. The industrial age was renamed the atomic age. Some 3,000 huge nuclear power stations were projectedworldwide by the year 2000, more than 500 of them in the developing world. These were not just the private dreams of nuclear proponents, but the collective energy plans of industrial and developing nations, blessed, almost without exception, by heads of state, planning agencies, finance ministries, and, of course, energy policy makers.

From the nuclear bureaucrat's perspective, the biggest problem lay in running out of fuel. Known deposits of uranium were believed to be scarce. Of these deposits only a fraction of one percent is usable uranium-235, the nucleus of which will break apart, or "fission" with an enormous release of energy in a reactor. The remaining 99 percent is uranium-238, which will not fission in a reactor. As recently as 1976, global uranium-235 supplies were thought sufficient for the lifetime needs of only 500 reactors, far below the 3,000 on the drawing boards. To fuel their lifetime needs required finding new deposits or a new nuclear fuel. It was the latter that captivated most nuclear planners, and the fuel was plutonium-239.

Plutonium-239 is not found in significant quantities in nature. It is produced when a neutron from a fissioning atom of uranium-235 strikes the nucleus of a uranium-238 atom and is absorbed by it. This minutely heavier atom becomes - in a matter of days - plutonium-239, which is just as fissionable as uranium-235.

In conventional reactors - sometimes called burners or converters - the plutonium is generated at a much slower rate than uranium-235 atoms fission. To take advantage of plutonium's best properties, it is removed from the used fuel of conventional reactors through a complex chemical process known as "reprocessing". Then it is fabricated into fuel and placed in the core of a new type of reactor. In these plants, plutonium would replace uranium-235 as the fuel, and the core would be surrounded by a "blanket" - as it is comfortingly known - of uranium-238. Neutrons emanating from fissioning plutonium would convert uranium in the blanket into new plutonium. Because this "blanket" plutonium was produced a bit more quickly than it was being burnt in the core, the plant was baptized a "breeder". This "nuclear fuel cycle" extended supplies more than 100 times by allowing - at least in theory - both uranium-235 and uranium-238 to serve as fuels.

But this little bit of wizardry invoked not Houdini, but Faust. The plutonium that was essential for the growth of nuclear power was the same stuff that destroyed Nagasaki, Japan. In 1943, worldwide supplies of plutonium were measured in microgram quantities. Soon, reactors would be making trillions of these micrograms in tens of nations around the planet. A small reprocessing plant could extract weapons material from power reactor fuel, or await the sale of plutonium fuels by reprocessors worldwide. All that lay between that and bombs was a college physics degree and a little metallurgy.

This should have been hugely disquieting to the nations that had committed themselves to nuclear arms control and to stopping the spread of these weapons to other nations. In 1956, the United Nations created an International Atomic Energy Agency (IAEA), which combined vigorous promotion of commercial nuclear power with a program of inspections - called "safeguards" - to protect nuclear materials from unauthorized use. By 1968, concerned that a global nuclear arms race could make superpower arms control even more improbable, the United States, United Kingdom, and Soviet Union together sponsored a pact - the nuclear Non-Proliferation Treaty, or NPT. The Treaty came into force on 5 May 1970; 127 nations have since ratified it.

The NPT called for the superpowers to control their own arms race and for all signatory nations to prevent the spread of nuclear weapons to other nations. Anxious not to close the doors on a growing industry, the industrial nations promised to provide preferential access to nuclear power aid to nations that foreswore nuclear weapons. "Atoms for peace" programs proclaimed that nuclear power would be so cheap and plentiful that developing nations could become economic equals without the leverage of the bomb.

As protection against the misuse of civil nuclear aid for weapons, the Non-Proliferation Treaty pressed signatories to allow IAEA inspectors into all nuclear facilities to certify that nuclear materials were not being diverted to weapons purposes. But the Treaty also held out the possibility - in Article V - that nuclear explosions could be "peaceful," as for mining, excavating, or exploring for gas and oil. Thus, all the necessary skills, programs, and experiments for nuclear explosives could be developed legitimately by a Treaty signatory. Turning explosives into bombs would be a political, not technical, decision.

Indeed the early euphoria of Western governments (and to some extent, the Soviet Union) was so great that many nations eagerly trained nuclear scientists from abroad in the minutiae of nuclear technology, and, of course, provided huge government subsidies to promote sales of nuclear technology abroad. In the excitement over this new global industry, "safeguards" were an afterthought. Nevertheless, in 1985, only six, not thirty, nations clearly possess nuclear explosives: the United States, the Soviet Union, the United Kingdom, France, China, and India. The last achieved that status in 1974, and officials deny that its "explosives" are bombs. Israel is a presumed member, as is South Africa, but neither had openly tested such devices, leaving to the speculations of the intelligence community the size and sophistication of their arsenals. But stability this is not; tens of nations, if not the PLO and IRA, could gain access to nuclear weapons in the next decade.

It may sound disingenuous to worry about five, ten, or a hundred new nuclear bombs when the superpowers have them by the thousands and are building more. But a Third World arms race, once begun, could both derail arms control and spark the detonation of superpower arsenals. Even a single explosion could remove the psychological barrier that has blocked every potential user of a nuclear weapon since August 1945.

In 1985, Pakistan, India, South Africa, Israel, Brazil and Argentina are perched on the edge of nuclear weapons programs. The last two have adopted civilian governments that appear much less committed to nuclear development than the military governments they replaced. Pakistan, on the other hand, has moved aggressively toward nuclear weapons capability. Prime Minister Rajiv Gandhi warned the US in June 1985 that "it would be a matter of weeks or months" for India to produce nuclear weapons following any nuclear test in Pakistan. Both Libya and Saudi Arabia have reportedly contributed financially to the Pakistani bomb program; one or both would presumably want some samples in return. In anticipation, Israel has reportedly deployed nuclear-tipped intermediate range Jericho missiles in the Negev desert and Golan Heights. Who can imagine serious superpower arms talks in such a world? Every nuclear nation could point to a wide range of potential adversaries to justify existing arsenals and weapons development programs. In contrast to the relative invulnerability of superpower arsenals, these weapons and nuclear facilities are exposed, making them attractive targets and more likely to be used. Delivery systems could range from cruise missiles to backpacks; "star wars" defenses, whatever their effectiveness, would be of little use. And many of the big nations that had decided not to build the bomb, including Japan, Federal Germany, Spain, Australia, and Italy, among others, could consider nuclear weapons programs essential to preserving their ways of life.

We have not set out to write a depressing or pessimistic book. That book, had we written it, could have been called *Plutonium 1975*. At that time, governments acknowledged that safeguards were inadequate, but simultaneously favored nuclear exports and widespread use of plutonium. Under such circumstances, the spread of the bomb was inevitable; the only policy issue was when and to whom. President Carter's laudable efforts to bring global attention to these issues fell prey to ingrained perceptions, even within his own administration, on the inevitable growth of nuclear power, reprocessing and the breeder. In 1985, such fatalism is both inappropriate and dangerous.

The political and economic attractiveness of non-nuclear energy strategies, unthinkable fifteen years ago, has been proven on paper and by example. Commitments to nuclear power have shrunk, even in centrally planned economies without anti-nuclear movements. Plutonium reprocessing and the breeder are no longer seen as inevitable, even in the European nations that seemed so bent on that future five or ten years ago. Stripped of their "commercial" cloak, the plutonium programs that do exist appear propelled by military motives or mindless inertia.

This book will review this rapid bit of nuclear evolution. It begins with a detailed exanination, in Chapter 2, of the current fortunes of nuclear programs in the key nations - the US, the Soviet Union, Federal Germany, France, Britain, Japan and some developing nations. The message of that chapter is that nuclear reactors are falling out of favor across as wide a range of differently managed nations as can be imagined.

Many of the reasons for this are specific to individual nations, but a number are generic. Energy demand in the industrial world is flat or shrinking and electricity use is growing at a small fraction of the rate that was once taken for granted. Nuclear plants, everywhere, are time-consuming to build, far over-budget, and often unnecessary and controversial. Most industrial nations see over-capacity dominating their electric grids for several decades, without new power plant orders, and aggravated by radical improvements in the energy efficiency of industries, homes, and commerce. Meanwhile, the same factors plus huge foreign debts that have drastically cut expansion plans affect many emerging Third World nations.

Thus, instead of the 600 standard-sized nuclear plants (each one thousand megawatts or one gigawatt in capacity) planned only ten years ago for operation by 1985, only the equivalent of 220 exist worldwide. Another 160 are under construction for operation by the year 2000. There may be new orders, as well as further cancellations, but the result is an industry very different in size and risk than one with 600 plants in operation and 2,400 under construction.

In ten years, the global nuclear industry has shrunk by about a factor of eight. Known uranium resources, meanwhile, have climbed several-fold while prices have collapsed to one-third their 1976 level. In the early 1970s, when breeders and reprocessing were considered essential for the continued growth of a nuclear industry, global uranium resources were guessed to be between 1.5-3.0 million tons. This would provide for 650 nuclear reactors operating for 30 years. Fearful of shortages and rising prices, utilities bought uranium contracts far into the future, often for plants they hadn't even begun to build. Today, known uranium resources could satisfy the needs of three-to-ten times the number of reactors in operation and under construction, for their lifetimes, with total electricity costs below that of breeders. The same glut holds true for uranium enrichment capacity, with government-operated plants in Europe, the US and USSR all cutting prices and eliminating contract penalties to cover their costs and win back business.

Accordingly, the number of projected plutonium fuelled breeders has fallen from about 400 to something like five. This collapse, its reasons and future prospects, will be examined later in this book, but it is assuredly good news for people concerned about the spread of nuclear weapons.

The disproportionate fall in plutonium's status makes sense. On the charts and graphs of the nuclear planners, plutonium breeders would begin to multiply only after uranium became scarce and expensive. There is nothing particularly magical about the breeder, or its ability to turn uranium-238 into usable fuel. If there had been, the nuclear planners would have skipped uranium-235 fuelled reactors entirely. Breeder reactors are more expensive to build, and construction costs are the dominant cost component of a nuclear plant during its lifetime. The fuel, once made in a reactor, must be extracted at reprocessing plants and fabricated into rods at special facilities. The costs of extracting and fabricating the uranium and plutonium in spent fuel into new rods are much higher than digging up raw uranium and enriching it for use in conventional reactors. When it appeared that breeders would come along more slowly than planned, plutonium proponents - particularly in the United States - sought to use this "recycled" uranium and plutonium in conventional reactors as MOX (for "mixed oxide") fuel. In Europe, policy favored saving the extracted plutonium for use in breeders, where its special characteristics could be put to better use. Plutonium breeder fuel, however, was even more expensive than MOX fuel, making the breeder the most expensive nuclear option in terms of both fuel and capital cost. The fuel discharged by breeders would require expensive, new, and sophisticated reprocessing and fuel manufacturing facilities. In sum, conventional reactors would be much cheaper to build and operate - at least until uranium supplies began to disappear and prices began to escalate. At that point, the reprocessing-breeder phase could be underway.

Today's nuclear industry makes the breeder look more like an index of national technological vanity than a thoughtful response to the energy problem. Reprocessing presents a thornier problem; as a means of extracting platonim from spent nuclear fuel it has always been essential for nuclear weapons programs. "Commercial" reprocessing has been considered a prerequisite for breeders and, in many nations, for an essential step in the management of commercial radioactive wastes. This 'melange' of national security, energy, technological development, and waste management drives interest in reprocessing.

Chapter 3 reviews the historical performance and current status of reprocessing plants around the world. The nuclear industry's shrinkage has vastly reduced the number of reprocessing plants that could have been operating by now, but it has not cut the number to zero. There is much more operating and planned reprocessing capacity in the world than there are plans for breeders to burn up the plutonium such plants could extract. Using the plutonium in conventional reactors is far less economical than buying and enriching raw uranium-235. In addition, all of the world's "commercial" plants face daunting technical and economic problems, even in nations that have not allowed marketplace considerations to dominate their nuclear decision-making. This leaves only two possible justifications for reprocessing - as a treatment for radioactive waste or as a means to add to nuclear weapons arsenals.

Understandably, utilities expected reprocessing plants to take away their nuclear waste as quickly as it was generated. Governments would take the waste from these plants and find some way to manage and dispose of it. But as reprocessing has retreated further into the future for economic (and technical) reasons, utilities face growing piles of waste and governments must consider direct disposal of spent nuclear fuel rather than disposal of the wastes from reprocessing.

In Chapters 4 and 5, we review the range of alternatives for managing the growing piles of nuclear wastes accumulating at reactor sites. Some are short-range options that buy time to find better solutions than we have today for the long-term isolation of radioactive wastes. Reprocessing, as we argue, cannot be considered useful for this task. Nor, as we describe in Chapter 5, does it make long-range management of radioactive wastes any easier - on the contrary.

In Chapter 6, we review the final "justification" for reprocessing - the production of plutonium for military purposes. Commercial nuclear fuels, as we have noted earlier, probably contain as much plutonium as exists in all military arsenals. Even with no new orders for nuclear plants, the quantities will climb. The letter of the Non-Proliferation Treaty and international safeguards admonish non-weapons nations not to consider using civil material for weapons. Weapons states are not prevented from doing this under the NPT, but it would do grievous damage to the spirit of the Treaty and further alienate non-weapons states.

Alas, in at least Britain and France, nuclear power and weapons programs have always been in direct collaboration, and more such plans are afoot. Old military reactors in the US and France are reaching the end of their productive lives in the eyes of both governments. In the US, the Reagan administration has repeatedly proposed mining commercial nuclear waste for weapons plutonium. In France, official sources have consistently proposed using a multinationally financed breeder reactor to supply plutonium for the French nuclear weapons program. There is much increased discussion of an independent European nuclear force linking Germany, France, the UK, and possibly other nations, with plutonium ostensibly produced for energy used instead for warheads. If consummated, these proposals would deeply undercut any efforts to keep nuclear power from contributing to weapons proliferation around the world.

Unfortunately, these proposals - and others, discussed at length in Chapter 6 - come at a time when all the precepts of the nuclear Non-Proliferation Treaty are under attack. The superpowers are at loggerheads on arms reductions. The long-promised benefits of nuclear energy for Third World development look more and more like hopeless fantasies. International safeguards are not taken seriously or applied equitably. In 1982, Israeli warplanes destroyed Iraq's Tammuz reactor because Israel had no confidence in Iraq's signature on the NPT or in the efficacy of the IAEA "safeguards" program at the plant. The bad examples set by Britain, France, and the US further undermine support for the Treaty.

Proliferation, in spite of all these problems, is not a case of a cat out of a bag. What matters about the spread of the bomb is not just "whether," but how often, to whom, how aggressively, with how much military sophistication, with what commitment to actual use, and with what resistance to disarmament. Tens of nations which could be developing bombs aren't, and the industry that was to bring others to that point has collapsed to an eighth its expected size in one decade.

The collapse of commercial nuclear power has provided a breathing spell that could not have come at a better time for the NPT. The industry's shrinkage has bought precious time for arms control efforts, for non-nuclear energy strategies, for strengthened international safeguards on existing nuclear facilities, and for preventing commercial separation and use of plutonium. Citizens groups working on these issues are active and influential in all the key nations. Threats are certainly there, but in all likelihood they will not destroy the Non-Proliferation Treaty. Without it, no international standards would govern any nation that wanted to sell or swap nuclear weapons technology with any other. It would be a world threatening not only to the superpowers, but the normal and underpowered as well; a world in which nuclear weapons could be as commonly used as conventional bombs are today. The NPT, however discriminatory, still has the support of the superpowers and is a proud, if tattered, standard for tens of nations that do not desire nuclear weapons themselves or promote them - even accidentally - to others.

Chapter Two

Nuclear Power Programs 1985

United States

"The failure of the US nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. The utility industry has already invested $125 billion in nuclear power, with an additional $140 billion to come before the decade is out, and only the blind, or the biased, can now think that most of the money has been well spent." So began a February 1985 article in Forbes magazine - long the most vigorous supporter of nuclear power among American business publications.

In part because of Wall Street's growing nuclear phobia, the US nuclear program in 1985 is often considered dead or dying. The number of plants in operation, under construction, or planned is smaller than it was 13 years ago. Some 95 nuclear plants have been cancelled over the past nine years, against 13 new orders. Most plants under construction are five-to-seven times over budget.

Nevertheless, with 85 operating nuclear power stations turning out more than 13 percent of the nation's electricity, the US program is - by a factor of two - the largest nuclear program in the world. Some 33 reactors are under construction. Together these 118 plants would generate 105,000 megawatts of power. Each also generates about 30 tonnes of radioactive spent fuel annually. Short of another Three Mile Island accident, the plants in existence will probably continue to produce highly radioactive waste for their entire commercial lifetimes - estimated at 30 years. The current US volume of highly radioactive spent fuel is about 12,000 metric tonnes, only a small fraction of the 95,000 metric tonnes that the units under construction and in operation would generate over their expected lifetimes.

As will be repeated in future chapters, one significant way in which the US nuclear enterprise differs from that of other countries is the extent of private sector involvement. American utilities are generally privately held and regulated by state government entities called public utility commissions. Nuclear reactors are sold by four private corporations, though the developrnent of these technologies was financed by the US federal government. Together, these vendors -- General Electric, Babcock & Wilcox, Westinghouse, and Combustion Engineering -- could supply 25-30 nuclear reactors annually from the mid-1970s nuclear manufacturing facilities. Even before the total collapse of US nuclear orders - none since 1978 - it is estimated that these vendors lost, conservatively, more than $2 billion on reactor sales.

Reactors are built by architect-engineering firms that sub-contract to hundreds of smaller supplier conpanies for pipes, valves, concrete, electrical equipment, engineering services, and so-forth. Nearly all of these firms contract with utilities on a cost-plus-percentage basis. In contrast to the vendors, most of these architect-engineering firms have made substantial profits on their nuclear business. Bechtel Corporation is the giant among these mammoth firms.

The role played by the US government in the nuclear industry is significant, though much less than in other industrial nations. To stimulate the entry of the private sector into nuclear power, the US government provided the "vendors" with open-ended reactor development contracts, provided for limits on liability of reactor operators arising from any catastrophic accidents, and encouraged private sector operation of fuel-cycle facilities (e.g., uranium enrichment and reprocessing) that had been dominated by the Defense Department.

The federal Nuclear Regulatory Commission regulates the safety of nuclear power stations - not their economics, which is a field left to the states. The federal Treasury also provides large tax incentives for utilities to purchase nuclear power plants. These can total 40 percent of the construction cost of a power plant, but are still not large enough to stimulate new nuclear orders. The federal government also provides for management of radioactive wastes.

With the possible exception of the Carter Administration, every US administration since World War Il - from Dwight Eisenhower's to Ronald Reagan's - has favored the rapid expansion of nuclear power through a shorter construction leadtime, rapid licensing with reduced public involvement, tax incentives for nuclear construction, federally funded liability insurance for nuclear accidents, government management of radioactive wastes, and rapid development of reprocessing and the breeder reactor. President Nixon made nuclear power the centerpiece of his Project Independence effort. Ford continued that effort, though he suspended commercial nuclear fuel reprocessing after his Georgia opponent in the 1976 Presidential election made the link between conmercial reprocessing and the spread of nuclear weapons a key campaign issue. President Carter stressed that nuclear energy would be a "last resort" energy alternative, and vigorously opposed the breeder and reprocessing in the US, Europe, and Japan. But the prescience of this position was not much appreciated abroad, by the US nuclear enterprise, by the US Congress, or even by his own Energy Department, which projected a quadrupling of nuclear capacity by 2000.

The Reagan administration faces a difficult problem with nuclear power. The administration would like to do everything it can to help the industry, but it faces the reality of substantial existing federal subsidies to an industry that is making an uneconomical embarrassment of itself almost daily. The Reagan administration sought to keep alive the Clinch River breeder reactor, which Carter had tried, unsuccessfully, to kill every year of his presidency. But the mounting price tag for the modestly sized plant - $7 billion at final count, with only nominal financial contributions from the nuclear and utility industries - led to its eventual death in Congress.

In 1980, the Reagan administration also sought to purchase and operate Allied General's nuclear fuel reprocessing plant in Barnwell, South Carolina. The administration proposed to use the facility for "competitive procurement" of plutonium necessary to meet the growing needs of the Defense Department for weapons-grade plutonium. A bi-partisan chorus in Congress, backed by the nuclear and utility industries, shouted down this proposal. Nuclear Regulatory Commission member Peter Bradford summed it up: "The average nuclear utility realizes that...most of its customers do not want the feeling that when they turn on their lights, they are also turning on the local atomic bomb factory."

The Reagan administration has also proposed rapid licensing provisions for nuclear stations, effectively reducing public involvement in these proceedings; government assistance for over-budget nuclear stations; and reducing Nuclear Regulatory Commission safety standards for existing units. To date these proposals have had little effect; with state control over most utilities, four consecutive federal administrations have found it nearly impossible to accelerate nuclear construction. The underlying revolution in the technologies and economics of energy use - both of which transcend US boundaries - was much more telling.

Among the most important factors in nuclear power's decline - and limited potential for a renaissance - are these: poor methods for forecasting electricity growth, the myth of an "all electric economy", huge increases in the expected cost and technical complexity of nuclear energy, and unexpected competition from a very wide and deep range of technologies that improve efficiency or supply electric power at less cost and risk than nuclear energy. Each of these issues was investigated, debated, and put forth by a vigorous anti-nuclear power movement that had ample legal and scientific expertise to advance these arguments before regulatory agencies, the courts, utility planners, the public, and the financial community. Taking each one of these issues in sequence:

Forecasts. Projections of electricity sales made in the mid-1970s for 1985 by government officials and the utility industry are proving high by the equivalent output of more than 200 powerplants. Electricity consumption has fallen from the seven percent/yr growth rates of the 1960s to less than one percent per year over the past three years, and overbuilding during the early 70s has left utilities with sufficient capacity to delay new plant commitments for years, if not decades.

The All Electric Myth. At the core of bad forecasting was the captivating notion of an "all electric economy," where all energy applications - heat, mechanical motion, lighting, and communications would be converted from fossil power to electricity. The concept was simple, but analysis was utterly absent. Electricity at its present cost (eight cents per kilowatt-hour) makes sense for lighting, communications, air conditioning, industrial motors, and a few other applications covering 8-15 percent of the energy used in the economy. But as a source of heat or liquid fuel, electricity at eight cents/kWh is costing the equivalent of $125 per barrel of oil -- no match at the present price of $25 per barrel, let alone natural gas at the equivalent of $18-20 per barrel, coal at about $11 per barrel equivalent, and many renewable heat and fuel sources at $10-50 per barrel.

Cost. Since the early 1970s, US reactor construction costs have increased at an inflation-adjusted rate of about 15 percent per year, compared to a rate of less than half that for coal plants, even counting the added costs of new pollution control technologies for coal plants that reduce emissions below that of the average oil-burning electric plant. Fires in nuclear stations (Browns Ferry), flooding of the containment (Three Mile Island), electric power failures (Crystal River), seismic protection (Diablo Canyon, among others), and multiple simultaneous instrument and equipment failures (Rancho Seco and TMI) have forced expensive and time-consuming repairs. Most US reactors are seven times as expensive as the plants utility regulatory commissions approved for construction.

Competition from coal. New "state of the art" coal units - like New York's Somerset plant or Japan's Takahara units - can cut sulfur, nitrogen oxide, and particulate emissions to a level well below those released by existing oil-fired electric plants. Using more advanced technology, combined-cycle coal gasification plants can burn relatively poor quality coals with air emissions well below existing and proposed federal standards, and without expensive scrubbers. These units cost less than the typical new US nuclear stations and resolve many of the objections to coal combustion. Similar technologies, many dropping in cost and increasing in performance, can be "retrofitted" to sharply reduce acid rain from older coal stations.

Competition from cogeneration. Industrial generation of electric power (cogeneration) is technically proven and generally cheaper than construction of new power plant capacity. In the United States, this source is capable of displacing more than a third of central station generating capacity and is limited only by the over-capacity of most utilities. In California alone, 1300 megawatts of cost effective (i.e., cheaper than existing power supplies, let alone new coal or nuclear plants), cogeneration, wind power, and small hydro plants have been added in the past four years. Another 5400 megawatts are well along in the planning and construction process, with sales contracts signed with utilities.

Competition from conservation. Over 85 percent of all electricity use is for lights and motors: lights in commercial buildings, appliances, and industrial drive. New high technology silicon chip systems in light and motor systems could save 30-70 percent of existing uses at a small fraction of the cost of producing electricity. This category of savings alone could, if fully implemented, reduce total electric power consumption over the next 15 years despite substantial GNP growth. Another component of "efficiency" is the structural change in industry toward high technology and away from material and energy intensive manufacturing.

Of course, these factors are variously forceful all over the world. For the United States, however, these factors have cut conventional nuclear expansion plans nearly ten-fold in a decade, leaving plutonium, reprocessing and the more expensive and complex breeder reactor without any markets until far into the 21st century, if ever.

France

France's official energy policy can be summed up in four words: all electric - all nuclear. With a strong tradition of central planning; government-owned entities providing electricity, reactors, fuel cycle services, nuclear research, and financing; limited competition from domestic coal resources; and no indigenous oil to speak of, France had all the ingredients for a successful nuclear program. Indeed, with 35,000 megawatts of operating nuclear capacity supplying 60 percent of the nation's electricity and another 29,000 megawatts planned or under construction, France has become the world's most nuclear-power-dependent nation.

Centralization - and the rather well-known French taste for bureaucratic autocracy - has made it work. The shape and scope of France's nuclear program are the mission of the government's Commissariat a 1'Energie Atomique (CEA) . The CEA owns half of Framatome, the nation's reactor vendor with a capacity to manufacture six plants each year. All fuel cycle facilities are entirely owned by the CEA, through its wholly-owned subsidiary Cogema, for Compagnie Generale des Materieres Nucleaires. Since the beginning of the 1970s, the French government has been committed to a nuclear energy policy involving as rapid an expansion of nuclear capacity as 'les Finances' would permit, reprocessing of the spent fuel, use of the separated plutonium for breeder reactors, and vitrification of the high-level liquid wastes from reprocessing for permanent isolation. Decisions on nuclear growth are made by the President of the Republic. It was not always so smooth-running.

As in the United Kingdom, France's first reactors utilized natural uranium fuelled gas-graphite designs. The first six of these plants were built at Marcoule and Chinon, beginning in 1956, under the supervision of the CEA, both for electricity generation and production of military plutonium. Also at Marcoule was the CEA's UP1 military reprocessing plant.

The CEA's gas-graphite reactor design did not suit the interests of France's powerful state-owned electric utility company, Electricite de France (EdF). Noting a growing international interest in light water reactors, EdF sought to use US light water reactor designs as the basis of the French nuclear program. Licenses for both boiling and pressurized water reactors were soon acquired by French conpanies. The CEA, however, insisted that future reactors be gas-graphite plants. To resolve this rift between agencies, de Gaulle - who favored French technology over imported equipment - created a commission to recommend a reactor choice for France. It was known as the Commission Consultative pour la Production d'Electricite d'Origine Nucleaire, or, less tongue-twistingly, the PEON Commission.

At length EdF convinced the PEON Comnission to recommend, in December 1968, construction of at least one light water reactor. With the less nationalistic and newly-elected Georges Pompidou in power, the CEA was restructured and a new director sympathetic to EdF's needs, Andre Giraud, was brought in. With Giraud's strong leadership, the utility got carte blanche from the CEA for a light water reactor program with reprocessing and breeder reactors. It would be based initially on Westinghouse's pressurized water design which was being produced in France by the then-privately held firm, Framatome.

Backed by the high-level PEON Corrmission and Giraud's influence over a succession of French Presidents, EdF gained extraordinary authority over the Planning Ministry and even the French Treasury. This was most clearly symbolized in 1974, when EdF signed a seven billion franc contract with Framatome for nuclear power stations that was the largest contract ever signed in the world. The investments in power stations and fuel facilities contemplated in the government's Seventh Plan - 1976-1980 - exceeded 70 billion francs, a staggering figure in itself; more so because it came during a period when most other nations were scaling back their nuclear expectations.

As Michel Bosquet wrote six years ago in Le Nouvel Observateur, "The choices (if there ever were choices) have been made in the secrecy of the ministerial cabinets, by experts deemed infallible, according to unknown criteria. Never has technology been so triumphant."

Thus, it is not particularly surprising that France is the one nation still pursuing commercial reprocessing, and, to a lesser extent, the breeder reactor as integral parts of national energy policy. However, all is not well in either the light water reactor program, or the breeder program, or in the link between the two - reprocessing - a topic we will discuss at length in Chapter 3. It should also be noted that France has thus far refused to sign the nuclear Non-Proliferation Treaty, though in a peculiar form of Gallic logic it has pledged to "act as if it had."

In part, Electricite de France has become a victim of its own success. Ordering reactors from Framatome at a steady rate of six units per year helped keep industrial capacity working smoothly, reactor costs down and built on schedule, labor unions happy, and equipment suppliers' books full. But the worldwide slowdown in electric growth rates has left EdF with an immense and growing debt, substantial capital-intensive overcapacity on the electric grid, thirty large units under construction or on order, and electric growth far too slow to mop up the growing surpluses. As American utilities have unhappily found, this set of circumstances can be disorganizing.

At the end of 1984, Electricite de France had a long-term debt of 234 billion French francs, annual capital requirements exceeding 40 billion francs for the foreseeable future, and annual losses on electric sales averaging 5 billion francs per year over the past three years. Its debt has more than trebled in four years, as a result of the huge nuclear construction program and limited capacity to raise electricity prices to pay for it. The utility is the largest single consumer of capital in Europe, and, for that reason, has been forced by the French Treasury into international markets for cash. France's international debt of $53 billion (end of 1983) makes it one of the most indebted nations in the world. As the French economist Philippe Lefournier pointed out in L'Expansion, "the huge size of that debt means that all the money France will be able to borrow in the international credit markets for a long time will go to service debt."

Why, with such support in the French goverriment, can EdF not raise electricity prices to pay for nuclear construction? Because it would drive the residential and industrial customers EdF is seeking hardest back to fossil fuels, notably natural gas, which France is also over-supplied with. The national oil company - Elf-Aquitaine - is scheduled to receive under firm contract 29 million tons of petroleum equivalent in natural gas in 1990; demand in 1990 is expected to total only 22 million tons. This surplus is about equal to the output of twenty reactors, and could sorely impede EdF's effort to convert existing gas users to electric power. The utility subsidizes these conversions to persuade consumers that it makes economic sense - at least to them and for the moment. As EdF director Marcel Boiteux commented recently, never in the utility's 39 year history has it been in worse financial shape.

Thus, in 1983, under the chairmanship of Noel Josephe, the long term energy planning group preparing the Ninth French Economic Plan (1985-1990) recommended a future of no new reactor orders for the next nine years, even under electricity growth forecasts of 4.7-5.5 percent per year - three times higher than the 1980-1983 record. Nuclear power already generates about 60 percent of the electricity on the EdF system, and new plants entering service cannot be fully utilized - "baseloaded" in utility jargon.

As the Josephe report concluded, "Only the need to consider the safeguarding of the (capacity of Framatome - with its 7900 employees - to produce reactors) dictates the maintenance of a minimum (ordering) program spread out over a significantly long period...the (need to preserve this industrial capacity) is the only reason not to interrupt nuclear ordering altogether."

In a 1983 book titled Nuclear Power Struggles, Mans Lonnroth and William Walker described France's predicament: "Facing the heavy capital charges on its nuclear programme, and the need to keep electricity prices down to expand demand, EdF can ill afford to build further redundancy into its electricity generating system. It risks a vicious circle of rising costs, higher electricity prices, and even lower growth rates. A long period of drought therefore seems imminent for the French nuclear industry."

Conservation and efficiency inprovements, industrial cogeneration, and other cost-effective energy options have been seen as threats to the French nuclear program, and have until recently been given short shrift in energy planning. When Mitterand came into power, he created a powerful new proponent of renewable energy and conservation in the Agence Francaise pour la Maitrise de l'Energie. The AFME has already challenged EdF for dominance in French energy planning, and, in particular, in the subsidies the utility is allowed to provide to stimulate electricity use.

With the prospect of higher rates and limited access to capital for new capacity, EdF's policy of 'tout electrique - tout nucleaire' is in serious trouble. Industrial customers are not likely to convert to uneconomic electric resistance heating for processes, particularly in a decade of declining world fossil fuel prices. Similarly, residential users are not eager to convert to higher priced electric power, and EdF is losing its capacity to subsidize this "fuel switching" further. Recognizing these problems, the utility has recently turned to exporting electricity at rates below the full costs of production to cover its debts, but this is a politically risky market that is limited by power surpluses in many other European nations. In light of the weak franc and very limited capacity to increase international debts for a program with negligible payoff, France's nuclear program is trembling in the balance. To be sure, this is far from the end of French nuclear power generation; further still is the end of France's waste problem.

Caught by this contraction are the breeder and plutonium reprocessing. Until recently, French energy planners - indeed nearly all European energy planners - insisted on "saving" the plutonium extracted from light water reactors for eventual use in breeders. But with only one or two breeders now projected for operation by 2000, Cogema has lost its commercial market for the plutonium it extracts at La Hague. Based on the current nuclear program, and Cogema's hopes for successful operations at La Hague, over 50 metric tons of separated "surplus" plutonium are projected to arise by 2000 from reprocessing of French reactor fuel.

We will come back to the nuclear weapons implications of this problem in later chapters. At present, EdF is not at all keen to buy plutonium from Cogema at any price higher than the equivalent world uranium prices. Cogema, meanwhile, wants to price plutonium fuel based on the costs of producing it, meaning reprocessing and plutonium fuel fabrication. At the end of May 1985, EdF reached an agreement with Cogema to recycle about 2.5 tonnes of plutonium over the next five years. The utility will pay a premium over natural uranium prices, but not much of one, and the plutonium "consumed" in the agreement is only a small fraction of the projected surplus. Failure to reach agreement over the remaining plutonium produced at La Hague - or to find overseas customers - could halt Cogema's reprocessing plans and conceivably civilian reprocessing in France.

There are also growing rifts between EdF and Framatome over reactor orders. Framatome has argued that it must raise its prices on the plants it is building for EdF - by as much as forty percent - because the utility is ordering at a rate far below the six plant per year level needed to keep the reactor vendor working at full capacity. Framatome still has a substantial backlog of orders - 30 - out of 65 that have been bought by EdF to date. But the vendor is already planning to lay off about a third of its workforce in response to reduced domestic orders. It has - along with its breeder subsidiary Novatome - begun to diversify away from purely nuclear activities. Similar problems are accumulating with EdF's construction crews and the hundreds of subcontractors that need regular orders to stay in the nuclear business.

Rifts are also opening in other parts of the French energy establisment. EdF's nuclear over-capacity has forced the government-owned coal company, Charbonnages de France, to cut back production, close mines, and fire some of its 67,000 eniployees. The resultant political outcry forced EdF to sign a long term contract with Charbonnages de France committing the utility to purchase a fixed amount of coal for electricity generation.

Probably of greater potential impact, however, is a looming contest with Elf-Aquitaine over the residential and industrial heat market. The oil company cannot avoid price cutting on fossil fuels to help reduce the present surplus; this will surely erode EdF's desired plans to put electric heating in nearly all homes and electric process heating in as many industries as possible. As noted earlier, France's new energy conservation agency, the AFME, is not especially eager to solve EdF's overcapacity problem.

Under the present circumstances, EdF is understandably reluctant to invest aggressively in breeders. At present, France's 1200 megawatt Super-Phenix 1 breeder, at Creys-Malville in southern France, is four years behind schedule and far over budget. The plant is owned by an international consortium, called Nersa (for Societe Nucleaire Europeenne a Neutrons Rapides, SA), of which EdF has, at 51 percent, the largest share. Other owners include Enel, the Italian national utility, at 33 percent, and SBK, a Federal German company co-owned by utilities in the Netherlands, Belgium, and Germany.

With construction well underway in 1978, the estimated cost of the plant was six billion French francs with commercial operation slated for 1982. Originally, six replicas of Super-Phenix were to be ordered in 1983 for completion by 1990, but rapidly rising costs for unit 1 forced a re-evaluation of this strategy. Instead of building six replicas, Nersa would build Super-Phenix 2 with the same physical dimensions of unit 1, but with higher power densities and lower safety margins, and 1500 megawatts of power. Watching this process with growing concern, EdF began to insist on a full year of operating experience at Super-Phenix 1 before it graduated to a larger and less forgiving plant.

Recent delays at Super-Phenix 1 have only amplified EdF's concern. In April 1985, Nersa estimated that the plant would cost about 20 billion French francs and be operational by early 1986. The consortium simultaneously announced that serious unexplained vibrations had been found in the core as it was filled and heated to near operating temperatures with its coolant - liquid sodium. Nersa believes that it has the problem resolved and that Super-Phenix will join the electric grid by April 1986, but the escalating costs, unexpected vibrations, and delays have evidently rattled the plant's prospective owner.

EdF has stuck firmly to its original position of refusing to order a second breeder from Framatome's breeder design subsidiary, Novatome, until it has "at least" one year of experience with Super-Phenix 1 - the "at least" having been added rather recently. In early 1985, EdF cut back its design contract with Novatome despite the latter's warning that this would prevent the Super-Phenix 2 design from being completed before 1987. Now the earliest possible date for a second order has been pushed back to 1987, and EdF director Marcel Boiteux has recently conceded that breeders could not be commercially viable before 2000.

The French have argued that the breeder could become competitive with conventional nuclear stations if it could be built at a cost 20 percent above that of typical nuclear stations, and its fuel reprocessed cheaply. At 20 billion francs, Super-Phenix will cost about twice as much as a conventional, and at this point unnecessary, nuclear station. Its electric power will be more than twice as expensive as power from conventional reactors, in which France is already drowning. Its fuel, far from being cheaper than natural uranium, will cost two to three times that of raw uranium because reprocessing costs have risen so steeply. It may "breed" some plutonium if it runs well, but it does little good to "breed" something that is far too expensive to use - at least for power.

Federal Republic of Germany

The German nuclear progran is afflicted with problems quite similar to those facing the American program. There is nearly fifty percent overcapacity on the electric grid, slack demand for electric power (less than 1 percent per year growth since 1980), public opposition to new nuclear capacity, and a growing recognition that new reactor orders are not in the offing.

This view is, of course, not shared by the nuclear energy establishment in Germany, and is a far cry from the nation's' official energy plans in the early 1970s. At that time, forecasts called for 45,000 megawatts of nuclear capacity to be operational by 1985, including two breeder reactors and one large reprocessing plant. In 1985, Federal Germany can count 15,500 megawatts of nuclear capacity, none of which breeds, and only highly controversial plans for reprocessing. Because of a de facto moratorium on nuclear orders that ran from 1979 to 1983, only seven units totalling less than 7,000 megawatts are in various stages of completion. The Christian Democratic government officially supports expansion of nuclear capacity, government support for breeder development, and rapid construction of a small reprocessing plant in Bavaria, the stronghold of its political ally, the Christian Social Union.

Unlike the US and French programs, which arose from military roots, the German nuclear program has an ostensibly entirely commercial history. In the treaty that ended Allied control of Germany in 1954, the Federal Republic agreed not to develop nuclear weapons on its own soil. Though a German weapons option has been advanced by some politicians - notably Franz Josef Strauss - and is technically within easy reach, the nuclear industry has not profited from the close connection to military budgets and facilities that marks many other nuclear programs.

On the other hand, industrial development in Federal Germany strongly favors technologies with large export potential, and it was this external market that guided the early planning of the nuclear industry, and justified large goverrment subsidies. Substantial and competitive coal deposits in the Ruhr and a historically strong commitment to industrial generation of power - so-called "cogeneration" - meant that the industry would have to be based heavily on export markets to utilize its full potential. Reactors in the FRG are designed and sold by the privately-held firm Kraftwerk Union, or KWU. The company has the industrial capacity to supply eight units annually, though it has fallen far short of this level recently. It was also taken as an article of faith that Germany would have to build and operate fuel cycle facilities for enrichment, fuel fabrication, and reprocessing - before offering such services abroad.

Unlike those of France, Federal German utilities are under mixed private and public ownership. The largest of these - RWE, for Rheinisches-Westfalisches Elektrizitatswerk - dominates the grid, producing about half the electricity for sale to consumers or to smaller municipally owned utilities. RWE has also been a vigorous proponent of advanced, plutonium-based reactors. It has the largest share in SBK (for Schnell-Brueter-Kernkraftwerkgesellschaft), the multi-national firm that owns 16 percent of the French Superphenix breeder. But SBK is also trying to build a smaller breeder, SNR300, long-delayed and far-over-budget at Kalkar, near the Dutch border.

Egged on by their respective nuclear research laboratories, the principal utilities of Belgium, the Netherlands, and Federal Germany formed SBK in 1972 to build the prototype Kalkar breeder at a cost then estimated at DM 1535 million. This demonstration would be followed by construction of a follow-on plant, known as SNR-2, which would be a replica of Super-Phenix. The original sponsoring utilities put up only a small fraction of the money, and that fraction declined as the costs rose, delays mounted, and the governments of Belgium, the Netherlands, and Federal Germany were asked to make up the difference. The plant is 80 percent complete as of April 1985, but its cost is estimated at DM 7000 million, of which about 25 percent is to come from its original sponsors, the utilities. The erstwhile SNR-2 has meanwhile resurfaced as Germany's contribution to a European collaborative effort on fast breeders, about which more will be said in later chapters.

In 1985, RWE and other German utilities have their hands full sorting through the costs and complications of the light water reactor program. In the mid-1970s, nuclear energy became an intensely controversial topic in the Federal Republic. It split the ruling Social Democratic Party in half; in 1979, 40 percent of the delegates to the party congress supported a permanent freeze on nuclear development. As a result, Chancellor Helmut Schmidt, who supported nuclear power, could not exact nuclear support from party leadership in the German states.

As a concession to the anti-nuclear movement, the Federal Bundestag passed several stiff nuclear safety laws, the most important of which required any new nuclear plants to have firm contracts in hand for long term management of radioactive wastes. In the past this was fulfilled by short-term secret contracts signed by the German utilities with Cogema for reprocessing at La Hague, but it became known that these contracts in no way bound Cogema to do anything but take temporary custody of the wastes. They could be returned unreprocessed, or reprocessed, in whatever form suited the French company, at whatever time seemed appropriate. In any event, German utilities understood that the clear intent of the law was to prohibit further construction of reactors until either or both reprocessing and final storage of wastes were available inside the boundaries of the Federal Republic.

Meanwhile, Federal Germany has only six plants under construction; another six have been proposed but no order has been placed since 1982. This situation has been buttressed by essentially flat demand on the German grid, growing interest in and development of industrial cogeneration and district heating, and rapid cost increases at nuclear construction sites. Furthermore, the nation has one of the strongest anti-nuclear power movements in the world.

As in France, signs of surplus have created rifts in the energy planning establishment. Growing energy efficiency and a surplus of coal and nuclear plants on the utility grid mean that there is virtually no oil used in German power generation -- 5 percent of the electricity output came from oil in 1982. As a result, nuclear plants have forced German utilities to reduce their purchases of coal from Ruhr and Saar mines. It is cheaper to reduce coal purchases than turn off a capital intensive nuclear reactor. But coal miners reacted quickly, extracting a long-term contract frcm the utilities that calls for minimum quantity purchases at about the present level through 1995. In exchange, German coal miners have agreed to moderate wage demands. But the agreement firmly discourages the addition of new nuclear capacity on the grid, because utilities would then be buying both the reactors and coal they need not use.

In addition to the competition with coal, German natural gas utilities also face significant surpluses from long-term no-exit contracts signed in the late 1970s. This includes, as in France, deliveries from the Siberian gas pipeline. As a result, gas utilities are eagerly entering the cogeneration market, supplying medium temperature heat to industries and cogenerated electricity to the power grid. Generating plant for private industry now represents about 18 percent of German electric capacity. Expansion of this base has been resisted in the past by German utilities, but recent political compromises have opened the wholesale power rmrket to a range of smaller-scale traditional and non-traditional power generating alternatives. Gas surpluses also make it difficult for electricity to capture more of the home and industrial heating markets.

All this makes life very trying for Kraftwerk Union, which has struggled for the past five to ten years to replace its lost domestic orders with exports. The vendor's best current market may be China, which has expressed an interest in four reactors. KWU's anxieties have led it to offer these units with "technology transfer," meaning that the Chinese, if they wished, could build subsequent plants to the KWU design without ordering them from Federal Germany. Many of KWU's more expansive export plans, however, have come a cropper.

During the last five years, KWU lost two reactor sales to Iran and DM 900 million in loans and equipment. While KWU succeeded in selling the Atucha 2 reactor to Argentina in 1979, that nation's growing debt problem and recent announcement of nuclear proliferative capability could force German or Argentinian cancellation of the sale. A contract to sell eight-reactors-plus-jet-nozzle-enrichment technology to Brazil has telescoped into just the two plants, Angra 2 and 3, which are now under construction. Compared with the eight orders per year that were expected, Germany now has no new orders and none backordered.

Federal German utilities and KWU, meanwhile, see that their only avenue to renewed domestic orders lies in a solution to the nuclear waste problem. At this writing, the German nuclear establishnent has proposed a small - 350 tonne per year - reprocessing plant in Bavaria, where Franz Josef Strauss' control may ensure state level approvals. KWU will be the lead contractor for this plant. But it is not clear that the utilities are particularly enthralled with the reprocessing option; it has the advantage of looking like something to do with a radioactive waste management strategy, but other alternatives - including dry storage of spent fuel - are also being explored, all of which we will come back to in Chapters 3 and 4. It would also not be operational until 1995.

The likelihood of a nuclear resurgence in Germany seems slim. Stable production frcm coal mines, overcapacity on the grid, excess supplies of natural gas, and cogeneration set the stage for a major confrontation over nuclear power's claim to priority treatment by the government. The ramifications of this confrontation can only be gauged in their full political significance if one understands that the industrial centers of coal production - such as the Ruhr and Saar - are traditional strongholds of the Social Democratic Party, which is now in opposition. Pressure is building for one of the two major parties to come out against nuclear power in Germany.

The United Kingdom

Britain has had a rhetorically aggressive nuclear power policy since the 1950s, but it has borne little fruit. Programs have been based on indigenous 'Magnox' gas-cooled reactors, indigenous advanced gas-cooled reactors (AGRs), and indigenous steam-generating heavy water reactors, none of which has proved less expensive than coal. The heavy water program was abandoned without even starting construction of a commercial plant. Current plans center on the construction of a pressurized-water reactor under license from Westinghouse, as the first of perhaps five such units. An inquiry into the proposed Sizewell B PWR ended in March 1985 after more than two years of hearings. The official report will not be completed until late 1985 at the earliest. Assuming government approval is granted, construction will not commence until mid-1986, if then.

In 1985 Britain has 35 operating power reactors. Twenty-six are small first-generation Magnox units; eight of these are dual-purpose military reactors producing both weapons-plutonium and grid electricity. The nuclear authorities announced in 1985 that the anticipated operating lives of the Magnox units were being extended from 25 to 30 years; but most if not all will still be shut down permanently before the end of the century. There are seven twin-reactor AGR stations; four of these are still under construction or in lengthy commissioning. All but two of the civil gas-cooled stations are owned and operated by the Central Electricity Generating Board, the other two by the South of Scotland Electricity Board; both these utilities are "nationalized" industries, set up by statute and responsible to the government. The UK Atomic Energy Authority, the government nuclear agency, owns and operates the 250 MW Prototype Fast Reactor (PFR) at Dounreay on the north coast of Scotland, and the 100 MW prototype Steam-Generating Heavy Water Reactor at Winfrith, Dorset, the first and last of its line.

Official British nuclear power policy continues to support the reprocessing of all types of fuel, and looks to eventual commercialization of the plutonium-fueled fast breeder. However, electricity demand in Britain has remained at almost the same level for more than a decade, actually falling rather than rising in some years. Electricity sales in England and Wales were 2 per cent lower in 1983 than in 1973. In consequence British nuclear power planners have long since ceased to argue that new nuclear units of any kind are needed to meet increased demand. They argue instead that new plant will ere long be required to replace existing plant, and that it will be in any case more economical to build this new plant now to displace old plant from the merit order. This economic argument has been strenuously challenged by skeptics aware of the abysmal track record of the British nuclear industry. British nuclear plants have almost invariably been extravagantly behind schedule and over budget, and have thereafter fallen far short of their intended design output.

Nor does Britain need new generating capacity to reduce consumption of oil or natural gas. By the early 1980s only ten per cent of Britain's electricity - about two per cent of national energy use - was from oil- or gas-fired electricity generation. Total national energy use has fallen more than 15 per cent since 1973, despite a 6 per cent increase in real GNP. Even though old plant is being retired early, the CEGB's current generating capacity exceeds peak electricity demand by nearly 40 per cent; completion of plants still under construction will push this overcapacity to more than 50 per cent by the late 1980s even without any further orders. The capacity of the smaller South of Scotland Electricity Board will be 90 per cent higher than peak demand.

The argument most strongly advanced by the British government and the CEGB executives stresses the need to diversify generating capacity from its present 80-plus per cent dependence on coal. In 1985, however, after the collapse of the longest coal-miners' strike in British history, this argument has turned against itself. The failure of the strike, and the absence of power cuts from its beginning to its end, has devalued the official argument that Britain needs more nuclear plant to avoid being held ransom by the coal miners.

In any case, many analyses indicate strongly that neither new coal nor new nuclear baseload capacity can compete effectively in cost in Britain against other alternatives. It would make far better sense to invest in industrial combined heat and power and improved energy efficiency, and to upgrade existing coal-fired plants for better economic and environmental performance. Set against this energy context, it becomes more difficult by the month to see any possible role for the plutonium-fueled fast breeder, no matter how far out the planning horizon is projected. The British government's stubborn insistence on reprocessing, plutonium and the fast breeder looks more and more like a civil cover for essentially military interests.

The Soviet Union

The Soviet Union began the 1970s with a very modest nuclear program and great hope for future growth. The 1971 five-year plan contemplated 30,000 megawatts of capacity in operation by 1980, and nearly 90,000 megawatts in 1990. Relatively limited supplies of domestic uranium are known to exist in the USSR, so breeders were viewed as an essential component of the program's future.

With no anti-nuclear movement, no requirement for cost-effectiveness in the program, and government control over financing, regulation, reactor design, construction, and site selection, one might expect to find a smooth running nuclear power program. But this expectation remains unfulfilled. The Soviet 1980 nuclear power goal fell short by two-thirds, leaving roughly five percent of Soviet electricity - about one percent of national energy use - supplied by the atom. With only 21,000 megawatts in operation in 1985, the 1990 goal has collapsed to a modest 33,000 megawatts.

The Soviet Union relies on two reactor designs, an RBMK which is a graphite-moderated, water-cooled reactor, and the VVER, which is a pressurized water cooled and moderated reactor similar to the US design. Official Soviet policy is fully committed to a growing nuclear industry, with reprocessing and breeder reactors. But only the VVER, which is more resistant to nuclear weapons use than the RBMK, is exported to client nations.

The USSR, reportedly, has no completely civilian reactors; that is, fuel from electricity generating reactors may be regularly used for production of weapons plutonium. There is also no known commercial reprocessing plant in the Soviet Union. Fuel not reprocessed is stored at reactor sites. Fuel from Soviet-supplied reactors operating abroad is returned to the USSR for storage or reprocessing. Labor and material shortages at power plant construction sites are legend. Slipshod quality control is also common in nuclear equipment manufacturing. Soviet industry is not geared to the production of the relatively small quantities of nuclear-grade piping, pumps, pressure vessels, or electrical equipment needed in an atomic power station.

As Soviet Academy of Sciences member Nikolai Dollezhal wrote in July 1978, "the equipment delivered by plants must be 'nuclear class,' as it has now become the custom to say. It is not possible to state that all is well in this respect. Although legalized standards and rules for the design and manufacture of equipment for nuclear power plants have already been in effect for several years, observance of a high technological level in production is not always satisfactory."

The proposed government solution to the industry's difficulties was to centralize reactor manufacturing and construction in a monolithic facility - Atommash - that would build eight complete units annually to be towed by barge up the Volga to sites in central Russia or down the Don to markets in Eastern Europe. It was the top industrial construction program in the 10th Five Year Plan, requiring the building of a new city at Volgodonsk and a steel fabrication plant, Energomash, for manufacturing nuclear grade steels. Begun in 1972, Atommash was to be completed by 1980 at a cost of $1 billion, and in full operation by 1985. Once it was complete, only small VVERs and the older gas-graphite models would be manufactured elsewhere.

Serious delays, engineering problems, and housing shortages at Atommash have provoked extraordinary attention from Moscow for several years. Only in recent months has the extent of the Atommash problem become clear. Soviet emigre scientist Zhores Medvedev recently reported that "the heavy foundations of the ... plant began to give way (in 1983) .... walls collapsed and serious accidents stopped the plant's operations". Both the Washington Post and New Scientist speculated in early 1984 that the plant must be moved or abandoned.

Why? Atommash, Energomash, and Volgadonsk were all built below the Volgadonsk dam and the 1,080-square-mile Tsimlyanskoye Sea. The dam's foundations were not sunk into fully impermeable strata, which has resulted in a rising water table downstream from the dam - undermining the town, Atommash, and the steel works. There is little that can be done to repair something like this, save fire everyone in sight and reorganize the nuclear industry, which is roughly what the Soviets have done. The Soviet Army has been called in to assist construction at reactor sites. Regarding Atommash, no international visits were allowed between late 1983 and July 1985; sketchy recent reports suggest that, at extraordinary cost, a new foundation has been sunk 75 feet underground to permit Atommash to operate eventually at about half its design capacity.

As mentioned earlier, the Soviet Union has placed heavy emphasis on the development of breeder reactors. Three such units do exist in the Soviet Union: BR-10, a 10-megawatt pilot plant at Obninsk in Siberia, BOR-60, a 60 thermal-megawatt facility in Dmitrovgrad, and BN-350, a 350-megawatt electric breeder at Shevchenko on the Caspian Sea. But the aggressive program has fallen far behind original expectations. BN-350 has suffered serious leaks in its steam generators, where sodium and water are separated only by several thousand thin steel tubes. Leaks cause explosive mixing of the two liquids; in 1974, this explosion was spotted by a US ERTS satellite. It has led to operation at much lower steam pressures and electric output than originally planned.

A follow-on breeder - BN 600 - was slated for operation at Beloyarsk in 1977, with a 1500 megawatt model slated for 1987, and serial production of large breeders beginning in 1990. A combination of problems has set these plans back: the uranium glut, including a huge stockpile of uranium in the Soviet Union estimated at 200,000 tons; the operating difficulties at BN-350; continuing setbacks in the light water reactor program that command bureaucratic attention, cost money, and delay the perceived need for breeders; and the lack of a commercial reprocessing plant to produce plutonium to "seed" the first breeders.

Similarly, the Soviet Union has only preliminary plans for radioactive waste disposal. Though official policy involves reprocessing, vitrification, and final disposal in granite formations, the first step (reprocessing) has already resulted in difficulties. A high level Soviet nuclear official told Nucleonics Week in late 1980 that researchers have found it difficult to produce reprocessing equipment that can operate effectively with fresh spent nuclear fuel. Away-from-reactor temporary storage sites and existing Soviet reactors are being used to handle domestic fuel and spent fuel returned from Comecon nations. No geologic site has been chosen for final disposal.

Japan

Like her Occidental opposite numbers, Japan a decade ago aspired to a rapid and wide-ranging buildup of civil nuclear power in all its manifestations. Like her Occidental opposite numbers Japan has subsequently scaled down drastically the targets set up earlier, under essentially every heading. In Japan perhaps more than in any other nuclear industrial country save the Soviet Union it is customary to overlook the failures as if they had not happened, and to claim whatever happens as success.

Apart from the one-off Magnox plant at Tokai Mura, bought from Britain in 1959, Japan's first generation of nuclear plants was built under licenses from Westinghouse and US General Electric. Since 1973, however, all the orders have gone to various permutations of the giant Japanese engineering firms Hitachi, Toshiba and Mitsubishi. In 1985 Japan has 14 PWRs, 15 BWRs, one aging Magnox reactor and one prototype heavy water reactor in operation; another four PWRs and six BWRs were under construction. This was far short of the program confidently presented in the mid-1970s; in late 1975 the official nuclear forecast for 1985 was 49,000 megawatts. As recently as August 1979, the target for 1985 fell to 30,000 megawatts, with 53,000 megawatts estimated for 1990, and 78,000 for 1995. By 1985 there were less than 22,000 MW in operation; the target for 1990 had shrunk to 34,000 MW, and that for 1995 to 48,000 MW. Japan's light-water reactors had an operating history verging on the humiliating. The more recent units - those coming on stream in the 1980s - had, to be sure, markedly more satisfactory capacity factors. But most of the older units, both PWRs and BWRs, had taken a decade or more to bring their annual capacity factors even as high as 60 per cent; in 1984 five Japanese units still had annual capacity factors lower than 60 per cent.

Other aspects of the Japanese nuclear program showed a similar gap between intention and accomplishment. From the outset Japan's long-term plans to move to plutonium fuel mirrored those of the US and Europe, for similar perceived reasons. Japan anticipated dramatic growth in electricity use; but Japan had no domestic fossil fuels, and foresaw meeting the expected demand with nuclear power. Uranium, too, had to be imported, and was expected to become ever scarcer and more expensive. Accordingly, Japan espoused the accepted nuclear view that thermal reactor fuel would have to be reprocessed and its plutonium recovered and reused.

The Japanese program was to include both mixed-oxide fuel for thermal reactors and plutonium-fueled fast breeders. In 1979 the President of Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) wrote that "The utility companies are preparing to establish a new private reprocessing company very soon. This will undertake the construction of the second Japanese reprocessing plant with a capacity of about 6 tonnes [of spent fuel] per day. This plant is scheduled to start construction in 1985 and operation in 1991. In designing and constructing it, the operating experiences of PNC's Tokai reprocessing plant . . . will be essential. . ."

It would also, by any but nuclear standards, be discouraging. The pilot reprocessing plant at Tokai

Mura had accepted its first spent fuel in 1977. It had been credited with a capacity of 210 tonnes per year; by June 1981, however, after a series of leaks and shutdowns, it had actually reprocessed only 106 tonnes in toto. It operated sporadically thereafter, until further major leaks in both dissolvers in 1982 and 1983 necessitated comprehensive repairs and replacements, not completed until 1985. Undaunted by this unpromising experience, the Japanese nevertheless set up the Japan Nuclear Fuel Service Company, and announced in 1984 that it would build a commercial reprocessing plant with a design capacity of 1200 tonnes per year, at Rokkashomura on the northern tip of Honshu island. Its proposed capacity was scaled down substantially from that anticipated five years earlier; it was planned to be in operation not in 1991 but in the mid-1990s.

While Japan's reprocessing activities floundered, its fast breeder plans made if anything even slower headway. The 50-MW fast breeder pilot plant called Joyo went critical in 1977, and was later upgraded to 100 MW. But Joyo was a reactor only, and included neither generating plant nor steam generators - the perennial Achilles heel of fast breeders. Even in the 1960s Japan's nuclear planners were proposing a larger fast breeder prototype, to be called Monju, that would be a genuine power plant. But as the years passed the various interested factions - government, nuclear plant builders and utilities - remained at loggerheads over the financing of this prototype; and Monju remained stubbornly on the drawing board. At length, in 1983, an agreement of sorts was reached, and construction of the 250-MW fast breeder prototype got under way. In 1984 the Japanese Atomic Energy Commission called for the utilities to start work on a full-scale 1000-MW fast breeder power plant. Ironically, however, the first problem to be studied would be a comparison of the two fundamentally different designs of sodium-cooled fast breeders, the "loop" design and the "pool" design. After same two decades of fast breeder research and development Japan had yet to reach a decision even on this basic feature.

Japan Atomic Power Company and Kansai Electric have plans to load two and four experimental MOX fuel assemblies respectively into their Tsuruga 1 and Mihama 1 plants. In the longer-term the Japan Atomic Industrial Forum has called for a steady increase in the use of mixed uranium-plutonium fuel; but even the JAIF sees no likelihood of this fuel being used commercially before the late 1990s. Be that as it may, and regardless of the unimpressive record of Japanese plutonium technologies to date, Japan continues to see plutonium in due course playing a key role in Japanese nuclear power. The reasoning behind this assumption grows progressively harder to fathom.

Developing Nations

The attractiveness of nuclear power to many developing nations is no accident. Since the Atoms for Peace rhetoric of the 1950s and '60s, developing nations have been told that their chance of achieving equal status with industrial powers depended on cheap power from the atom. Probably more important than the promise of bountiful energy was the symbolic strength and independence gained by nations that harnessed the atom.

Throughout these years, the atom had its own lobbyist in the Vienna-based International Atomic Energy Agency (IAEA). This UN agency was founded on October 26, 1956, well before the advent of the Non-Proliferation Treaty, to "accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world". A second order called for the IAEA to "ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose". The secondary nature of this order is exemplified in the agency's promotional budget for nuclear power that has long overshadowed its safeguards budget.

By the time the Nuclear Non-Proliferation Treaty was brought into force - in 1970 - a substantial amount of nuclear trade existed between developing countries and nuclear exporters, much of it governed only by bilateral agreements that discouraged use of nuclear aid for weapons purposes. Several beneficiaries of this aid refused to sign the NPT, or give firm promises that they would not develop nuclear explosives. Indeed, at that time, the US and Soviet Union were vigorously testing so-called "peaceful" nuclear explosives, and were therefore in poor positions to insist that nuclear explosives programs were necessarily of a military nature.

By 1974 the IAEA estimated that there would be more than 550,000 megawatts of nuclear capacity throughout the developing world by the year 2000 - producing more than half its total electricity - including 60,000 megawatts of fast breeders. The IAEA realized that about 70 percent of this capacity would be built in the "emerging" nations: Brazil, India, Mexico, Iran, South Korea, Taiwan, Argentina, and Pakistan. These countries might be able to afford nuclear units or have electric grids large enough to accommodate the smallest available reactors. Most of the remaining Third World nations would either have to await the development of "mini-reactors" or multiply their electricity demand many times to make use of a single reactor.

The next five years brought about a collapse in expectations. Even so, by late 1979, Argentina, Taiwan, South Korea, Mexico, and Brazil estimated that they would have a combined total of 125,000 megawatts of nuclear capacity in operation by 2000. These plans were cited by nuclear reactor vendors in Europe and North America as proof that falling domestic orders could be replaced by orders from abroad. By 1985, no such assurance can be given. Projections for the "emerging" nations are less than one fifth the level they were six years ago, and less than one-tenth the estimates of a decade ago.

The reasons are obvious. First, the once-emerging Third World nations have been set back decades by development policies that have left them with debts so large that they can barely pay interest on existing loans, let alone finance a multi-billion-dollar construction project ten to fifteen years long. Western lenders, even including government-owned export banks, cannot afford to finance more debt for dubious purposes to the world's most indebted nations.

The nuclear industry, for that reason, is being asked to finance nuclear exports directly. But, as Louis Tomasetti, executive vice-president of General Electric, told an Atomic Industrial Forun meeting in Washington, DC, in November 1984, "We have had no nuclear orders since the mid-1970s. (And what we see abroad are) financially unattractive projects that are often hopelessly encumbered with political considerations . . . . Customers frequently demand major financial concessions - such as total financing at incredibly low interest rates - or even own-and-operate schemes where the prime contractor takes the entire financial risk and gets paid as electricity is generated for the consumer. We do not intend to pursue unprofitable projects merely to be able to say that we have won a nuclear order. We don't need such expensive trophies to preserve our technical ability to support our customers. "

This does not mean, of course, that the nuclear industry is dead abroad any more than the absence of orders in North America and Western Europe means that. China, Egypt, Taiwan, Poland, South Korea, Israel and Turkey appear to have a continuing interest in nuclear power construction. Each is interested in US, French, or German light water reactors, though the financing terms involve considerable risk to potential reactor suppliers and government export-import banks. Meanwhile, plutonium-bearing wastes pile up just as inexorably in the south as they do in the north. Many developing nations have made no secret of their interest in developing nuclear explosives. India's bomb was built with material contributed both by Canada and the United States, under agreements that required it be restricted to "peaceful uses," a condition India evaded by calling its device a "peaceful nuclear explosive". Pakistan has covertly pursued nuclear technologies that can only be used for weapons manufacture.

Taiwan and South Korea have - at times - also pursued weapons programs, though both were reportedly brought to a halt by diplomatic pressures efforts during the Ford administration. Argentina probably has the Third World's most advanced nuclear program, having almost completed construction of a reprocessing plant at Ezeiza and a uranium enrichment plant at Pilcaniyeu. Eager not to annoy either European or American creditors, or his neighbors in Brazil, Argentina's first civilian President in well over a decade - Raul Alfonsin - has substantially cut Argentina's nuclear power and weapons program. But the program is also - as in Pakistan - a matter of continuing nationalistic pride. Development of weapons or an export industry could be only an election - or a coup - away. Like its neighbor Brazil, Argentina has not ratified the nuclear Non-Proliferation Treaty.

In Brazil, ninety per cent of the finances for the $30 billion nuclear program (eight reactors from Germany) were to come from abroad. With foreign debts topping $100 billion, only two of the eight units - Angra 2 and 3 - are under construction, and these are being delayed until the early 1990s because of financial difficulties. Some internal critics of the program, including the head of the Sao Paolo state energy company, Dr Jose Goldemberg, favor scrapping Angra 3 and the remainder of the German contract.

Mexico's nuclear program has never been known to include weapons interests. But, it too, has been virtually brought to a halt by growing debts and long delays and difficulties with the country's first nuclear plant Laguna Verde. Iran's nuclear program is similarly moribund; the half-built Bushehr reactors have become a target for Iraqi warplanes, and no further units are planned or under construction. Of course, the nuclear programs of Israel, South Africa, and nearly all the nations above command continuing attention from the superpowers. Several are a hair's breadth away from joining the nuclear club; and highly advanced computers - subject to export controls of dubious effectiveness - could make testing of some nuclear weapons unnecessary. But it is important in understanding the future of the nuclear industry and its potential dangers that these have been drastically altered by the industry's recent shrinkage.

There is also a growing realization among developing nation energy specialists that nuclear power cannot solve the Third World's most pressing energy problems: oil dependence, arising mainly from transportation, and firewood depletion, caused by rural cooking, often in open fires. Small scale, capital saving, renewable sources - wind for water pumping and rural electric generation, small hydro, agricultural, animal, and forestry residue use - offer manageable opportunities to address the wood and oil problems. Similarly, conservation and efficiency technologies from the developed world can often be applied straightforwardly in urban centers of the Third World. Office buildings are office buildings; and gasoline taxes can certainly be used to reduce unnecessary transport. Development and use of small oil, gas, and coal deposits that are uninteresting to multinational oil companies is a further option that is of great interest to the World Bank.

Transportation presently consumes 40 percent of all oil used in the Third World. Electricity generation is responsible for only 15 percent of petroleum use, most of that in small units connected to local grids. Nuclear electric plants can displace only those oil fired plants that run "baseload" - that is, nearly all the time - in grids that are very large, because of the instabilities that result if too large a unit shuts down on a small grid. Only fifteen nations in the Third World have grids large enough to accommodate the smallest available nuclear reactor. Even if these criteria are met, electricity is still an inadequate replacement for the petroleum used in transportation. It is also grossly uneconomic as an alternative to the oil, gas, or coal used in industry to supply process heat. As a substitute for cooking fuel, it is simply unaffordable. It cannot be delivered at any reasonable cost to the rural poor, nor can they afford the necessary appliances to use it.

Nevertheless, the majority of international energy aid to the developing countries is for electric power plants. In part, this reflects entrenched interests on both ends of the foreign aid system. On the Third World end, there is desire for the prestige associated with a large electric power plant, and for the industries it could conceivably attract. On the developed nation end, there are industries heavily dependent on export markets for their earnings. Another factor is the inertia of government-to-government aid programs that need not pass marketplace tests in either nation. And, of course, when reactors are involved - rather than large dams or coal plants - there is the potential for military use.

Certainly there are nations with serious interests in nuclear energy plants. But there is no consensus anong developing nations that nuclear electricity is a desirable thing to have, that it is necessary, or that it is affordable. The 60,000 megawatts of plutonium-fueled fast breeders that the IAEA saw in the Third World by 2000 are a fantasy.

Chapter Three

Reprocessing 1985

Reprocessing was developed as a key technology for the manufacture of nuclear weapons. It still is. Most modern nuclear weapons use plutonium as an essential fissile material. A chain reaction in the core of a nuclear reactor releases neutrons that turn some of the uranium in the core into plutonium; and the plutonium is separated from the uranium by a chemical process called "reprocessing". The five acknowledged nuclear-weapons countries all have reprocessing plants to separate plutonium for use in their weapons; see Table 1. India, which set off a nuclear explosion on 18 May 1974, made its "device" - a "peaceful nuclear explosive," according to the Indian government - using plutonium created in a research reactor and separated in India's reprocessing plant at Trombay. The Trambay reprocessing plant was not, however, constructed for weapons-purposes - at least not overtly. It was for "civil" reprocessing; the plutonium it produced was declared to be "civil" plutonium. According to nuclear people "civil" reprocessing is entirely distinct frem the military weapons activity out of which it emerged. In 1985, the comforting assertion does not bear close scrutiny.

The nominal civil justification for reprocessing spent fuel from power reactors had its origins in the late 1940s and early 1950s; for details see The Plutonium Business (Bibliography, page 00). At that time nuclear planners hoping to find a civilian application for their nuclear science and engineering were looking to the possibility of using the heat from a chain reaction in uranium to generate electricity. Unfortunately, as far as they knew, uranium was rare, costly and strategically acutely sensitive. Furthermore, less than one percent of natural uranium could support a chain reaction; the rest was useless. There was, however, one way out of this uranium dead-end. A chain reaction in uranium always turned some of the useless uranium, called uranium-238, into plutonium - which in its turn could sustain a chain reaction. This indeed was the whole military point of building and operating reactors. Ergo: the uranium fuel in a power reactor would, while generating electricity, also turn some of its useless uranium-238 into plutonium. This plutonium could then be separated from the uranium by reprocessing; and the separated plutonium could then be used to make more fuel.

Nor was this the extent of the possibilities foreseen. At the time nuclear designers were considering many different combinations of concepts and components for power reactors. Fuel made from separated plutonium could be used in the same reactors from which it had originally come. It could, however, also be used in another design - one that used much more plutonium in the core, and that produced much more plutonium in its own spent fuel. This design could even, in theory, produce spent fuel containing more plutonium than had been in the original fresh fuel. Because its chain reaction required so-called "fast" (very energetic) neutrons, and because the reactor could "breed" more new plutonium than it burned, it was called a "fast breeder" reactor. In the eyes of the nuclear planners, the combination of reprocessing and the plutonium-fueled fast breeder would bypass any future problems about the availability of uranium as fuel for power reactors. Plans for nuclear power - the generation of electricity based on the nuclear chain reaction - were founded from their inception on the premise that plutonium would have a key role in civil nuclear technology just as it had in military.

Whether in fact there has ever been, or can ever be, any genuine distinction between "civil" and "military" nuclear activities, if they involve the separation and use of plutonium, will be discussed in Chapter 6. In 1985, however, it is evident to any but the most purblind plutoniun advocate that the role foreseen thirty years ago for "civil" plutonium in nuclear power generation is long since discredited. As has already been discussed in Chapter 2, the world nuclear power industry has failed dramatically to expand as was expected even a decade ago. Uranium, far from being in short supply, is already in embarrassing glut. The fast breeder has proved to be a dauntingly expensive and unreliable design of reactor. Worst of all, "civil" reprocessing has proved to be an extreme challenge, both technically and financially.

Reprocessing for Bombs and Power Plants

The distinction between the original military technology of reprocessing and the later, purportedly "civil," technology begins with the material discharged from a reactor. Bomb-makers like their weapons-plutonium to be as nearly as possible pure plutonium-239, which results when an atom of uranium-238 absorbs one neutron. However, as a chain reaction continues to run, the accumulating atoms of plutonium-239 may themselves absorb further neutrons, and turn into so-called "higher isotopes": plutonium-240, -241, and -242, which lower the quality of the plutonium as bomb-material.

Accordingly, reactors that produce weapons-plutonium discharge their core-material after only a few weeks or months of operation. The core-material contains, of course, comparatively little plutonium after such a brief chain reaction; but the plutonium is well over 90 percent plutonium-239 - very well-behaved and predictable for bombs. Such an arrangement, however, has very little in common with that for reactors operated to produce electricity. Operators of such "power reactors" want to run them for as long as they can on a given load of fuel, both to get the most possible energy out of each fuel element and to keep the plant in service at peak output, earning income by generating saleable electricity. At length, of course, the proportion of fissile atoms in the fuel decreases to an inadequate level. For modern power reactors, this may mean that the fuel has been in the reactor for upwards of three years. After this long chain reaction it has undergone what is called a "high burn-up." This so-called "spent fuel" from a power reactor consists not merely of left-over uranium-238 and uranium-235, a small increment of plutonium-239 and a smattering of broken fragments of split atom called "fission products." Instead the plutonium in spent fuel may be less than 70 percent 239, the rest being higher isotopes. There will be less than one-third as much fissile uranium 235. Both the uranium-235 and the plutonium will have been significantly "burned up," leaving behind a complex mixture of fission products - dozens of different kinds of atoms, mostly unstable and "radioactive".

Early designs of power reactors, especially those used in the UK and France, used fuel made from rods of uranium metal. This metal fuel had a very low melting temperature; reactor fuel was burned only slightly longer than weapons fuel. The total number of fissions it could undergo was comparatively limited. At best a power plant operator could extract perhaps 5000 megawatt-days of heat energy from a tonne of uranium metal fuel, before it had to be removed and replaced. Modern power reactors no longer use uranium metal in fuel. They use a form of ceramic uranium oxide, which is much more durable than the metal. Oxide fuel therefore can withstand a much longer chain-reaction, and reach a much higher burn-up. The fuel used, for example, in today's pressurized-water reactors (PWRs) is intended to produce some 33,000 megawatt-days of heat energy per tonne before being discharged.

For power plant operators this is of course a welcome trend: the more megawatt-days per fuel charge, the more electricity and the more earnings. This high burn-up, however, brings in its train major complications once the spent fuel is discharged fran the reactor. The higher the burn-up, the more fission products, and thus, the more radioactive the spent fuel. This radioactivity is not only more intense but longer-lasting, coming as it does from the accumulation of those fission products with comparatively long "half lives." Particularly troublesome ones include strontium-90 and cesium-137, with half-lives of about 30 years; and a group of insoluble metals, including ruthenium and rhodium. There are in all about a dozen fission products that make civil spent fuel unpleasant and difficult to cope with.

The radiation from these fission products presents, of course, a serious biological hazard. Spent fuel must always be kept isolated behind some form of radiation shielding, to protect those working in its vicinity. But the radiation also presents a severe technical complication for any subsequent treatment of the spent fuel - especially reprocessing. Separation of uranium and plutonium from fission products involves dissolving the spent fuel in acid, and carrying out a series of chemical processes with different solvents. Metal fuel of low burn-up, like that from military production reactors and the old British and French civil gas-cooled reactors, is comparatively manageable. But oxide fuel of high burn-up, like that from present day power reactors, is something else again.

The fuel must first be chopped into small pieces, in a mechanical shear capable of severing an entire fuel element. This shear must be not only powerful but reliable over long service, since it will be operating in a sealed chamber or "cave" filled with lethal quantities of radioactivity, into which no maintenance staff can enter. All maintenance must be "remote," using special handling gear. The chopped up fuel - cladding and all - falls into a "dissolver" filled with a nitric acid solution; a filter basket catches the solid rings of chopped cladding, to be lifted out and sent for storage as solid "high-level" radioactive waste. The acid solution of fuel-material then passes into a sequence of chemical vessels - so-called "pulsed columns" or "mixer-settlers" - that blend the acid solution with other solvents to separate the fuel constituents. The radiation from the fission products attacks not only the solvents but also valve seals and other parts of the plumbing, including the metal vessels themselves.

Reprocessing high-burn-up oxide fuel also faces a more subtle problem. Certain fission products like rhodium are metallic, chemically similar to gold, and essentially insoluble, even in hot nitric acid. If a chain reaction runs long enough, these fission products accumulate to form tiny metallic granules in the spent fuel. The granules are not only insoluble but fiercely radioactive. If they are allowed to settle out onto the pipework or process vessels in a reprocessing plant the result may be disastrous. In September 1973, a layer of such granules led to an explosion that destroyed the first oxide-fuel reprocessing facility at the British site at Windscale. The most accepted explanation for the explosion is that the granules settled out after normal operation, and heated themselves up to a temperature of between 200-300 degrees Centigrade. When the plant was restarted, a product of the nitric acid and tributyl phosphate known as "red oil" reached the hot ruthenium particles, exploded, and then ignited some zirconium particles. The radioactive mess left behind forever halted further reprocessing at that Windscale plant. Accordingly, since that time reprocessors have attempted to devise ways to remove the fission-product granules using filters or centrifuges. The centrifuges themselves however are vulnerable to maintenance problems; their long-term effectiveness has yet to be established.

The Reprocessors

Despite this formidable catalogue of technical challenges, a number of countries have embarked on reprocessing for ostensibly civil purposes; see Table I for a list of countries and facilities; for further details see The Plutonium Business. The first reprocessors were the national agencies charged with manufacturing and separating plutonium for nuclear weapons. In the US the responsible agency from 1946 to 1975 was the US Atomic Energy Commission. In the UK the original agency was the Division of Atomic Energy Production of the Ministry of Supply; in 1954 the task was taken over by the newly-established United Kingdom Atomic Energy Authority. In the Soviet Union the relevant branch of central government was, and still remains, the State Committee on Atomic Energy. In France the responsible agency from 1945 to 1976 was the Commissariat a l'Energie Atomique.

For US readers one point must be stressed. The US Atomic Energy Commission relied heavily on corporate contractors to operate its various facilities, including Oak Ridge, Hanford and Savannah River. The other nuclear-weapons states however set up agencies that not only owned and controlled the various research and production sites but were themselves responsible for the day-to-day running of the sites, as well as for their management and finances. This consideration applied to all the activities pursued at these sites, including reprocessing; and it continued to apply for many years, long after the focus of nuclear activities broadened to embrace civil as well as weapons-related nuclear activities.

Outside the US civil reprocessing has remained largely a government responsibility: its management and finances directed and mediated by governments, its investment and marketing policy referred to governments, and its physical installations largely owned, directly or indirectly, by governments.

Such is the case in both the UK and France, in the Soviet Union needless to say, and in every Third World country thus far to embark to actual construction of reprocessing plants. It was also true for the first unambiguously "civil" reprocessing plant in Europe, built at Mol, Belgium, by a coonsortium of thirteen OECD countries under OECD auspices with funds from the participating governments. In Federal Germany, to be sure, four major chemical compantes in 1970 set up a subsidiary under the acronym KEWA to build a civil reprocessing plant. By 1974, however, the economic prospects for this plan looked so unpropitious that the four companies abruptly abandoned the idea. Faced with the legal necessity, under the German "Atomgesetz" or atomic law, to ensure availability of reprocessing for their spent fuel, the thirteen privately-owned electrical utilities banded together in the mid-1970s under the acronym DWK to undertake construction of one or more reprocessing plants. DWK has been in existence for a decade; it has yet even to get the first stage of permission to erect a plant. In Japan, the nine electrical utilities likewise set up a joint company to provide them with reprocessing of their fuel. It has thus far been a less than signal success, as will be described below. With these three exceptions - the US, Federal Germany and Japan - reprocessing has not even been regarded as an appropriate activity for private industry on its own.

The two countries with the longest experience are the UK and France. They are also regularly cited in 1985 as examples to prove that civil reprocessing is technically feasible and commercially profitable. Closer examination of all these efforts puts the matter in a rather different and less persuasive light.

Britain and France - "Civilitary" Reprocessing

The first reprocessing plants in Britain and France were the B204 plant that started up at Windscale in 1952, and the Usine Plutonium-1 (UP-1) that started up at Marcoule in 1958. They were military plants, like the vast Savannah River plant of the US Atomic Energy Commission. Thereafter both Britain and France built further reprocessing plants, the British B205 plant also at Windscale and the French UP-2 plant on the Channel coast peninsula called Cap la Hague. These plants were constructed to reprocess metal fuel from the gas-cooled "Magnox" reactors of the first civil nuclear power program in Britain, and the French equivalents. On the face of it both plants were therefore "civil" plants. In fact, however, the French government always considered that the plutonium from French gas-cooled reactors was available for use in weapons, even though it had been produced in nominally "civil" nuclear power plants. It has recently become public knowledge that a similar ambiguity shadows the plutonium from British "civil" Magnox reactors, as described later. In any case the B205 plant at Windscale also reprocessed the fuel from the Calder Hall and Chapelcross military reactors; indeed in 1985 it still does so, amid mounting controversy, as discussed below.

The dual role of these plants led French critics to label them "civilitary" installations. In the absence of information about the highly secret military reprocessing activities, it is invalid to cite either B205 or UP-2 as examples of long-term technical or commercial success. Even the information publicly available casts serious doubt on any such claim. The present operators of B205 (see below) carry a note in their accounts each year to cover anticipated losses on long-term reprocessing contracts negotiated in the 1960s. The financial status of French gas-graphite reprocessing remains obscure, not least in the value assigned to the recovered plutonium. Magnox reprocessing in the B205 plant in Britain encountered a cumulative technical problem in the early 1970s (see The Plutonium Business) that eventually required the construction of an entire new plant, still incomplete in 1985. No one knows how much-this plant will cost, or who will pay for it. British electricity supply organizations, its putative customers, have yet to agree to terms or sign any contract for its services.

As with metal-fuel reprocessing, Britain and France were early in the field with plants for oxide-fuel reprocessing. In 1971, Britain, France, and Federal Germany formed a joint company called United Reprocessors, to divide up the international market they then anticipated. In Britain and France, the oxide-fuel plant was added as a "head-end" pretreatment plant to the existing "civilitary" metal-fuel plant described above, at Windscale and Cap la Hague respectively. Neither plant was exactly successful.

The Head End Plant at Windscale was a reincarnation of the original B204 military reprocessing plant. Sited next door to the new B205 separation plant, the B204 Head End Plant incorporated new hardware to chop up and dissolve oxide fuel, so that the resulting acid solution could be fed into the B205 separation plant across the roadway. The Head End Plant started up in 1969, with a declared capacity variously stated as 100 or 300 tonnes of fuel per year; it was acclaimed by its operators as a technical triumph. It had been constructed nominally to reprocess oxide fuel from the second British nuclear power program, the so-called advanced gas-cooled reactors (AGRs). But the AGR power plants were falling disastrously behind schedule; not one even started up until 1976. The British reprocessors therefore sought contracts with foreign customers, including Belgium, the Netherlands, Federal Germany, Spain, and Sweden. Ere long spent oxide fuel from foreign customers was arriving in the storage ponds at Windscale.

By the sumner of 1973, for various reasons, despite its declared capacity, the Head End Plant had reprocessed a total of only 100 tonnes of fuel in its four years of operation. Be that as it might, its operators were aggressively seeking foreign business, and planning to expand its capacity to 800 tonnes per year. Then, on 23 September 1973, an unsuspected layer of highly active sediment granules in a process vessel caused a serious explosion that blew radioactivity out through a shaft seal into the air of the plant. Thirty-five employees were contaminated. The plant was shut down pending investigation by the official Inspectorate of Nuclear Installations. Senior company executives asserted that the Head End Plant would soon be back in service. At length, however, four years later, they disowned it, declaring that it was too old and unreliable to be reopened. Instead the company proposed to build a new plant more than four times the size. Critics wondered whether it might not make better sense to demonstrate successful operation of a small plant first.

THORP

Even before the official investigations had established the cause of the accident in the Head End Plant, the operator, British Nuclear Fuels Ltd (BNFL) was aspiring to greater things. In the autumn of 1974 a senior BNFL executive revealed that the company was contemplating building not one but two new oxide fuel reprocessing plants at Windscale, each with a capacity of some 1000 tonnes per year - one to service domestic nuclear plants and the other dedicated to foreign customers. The proposal continued to percolate and evolve until, in October 1975, a British tabloid newspaper published a sensational and inaccurate story calling it a "plan to make Britain the world's nuclear dustbin" - British for trash can.

In the months that followed, the issue flared into national controversy - the most intense public controversy about civil nuclear policy thus far seen in Britain. In March 1976 the then Labour government granted BNFL investment approval to proceed with plans for what was now to be a single large plant. It was to be called the Thermal Oxide Reprocessing Plant - THORP; and half of it was to be paid for by a consortium of nine Japanese utilities, whose spent fuel it would reprocess. But the public controversy continued unabated. After stonewalling throughout 1976, the government in December 1976 abruptly conceded that the THORP proposal needed more detailed discussion. A judge of the British High Court was appointed to head a "public inquiry". The Windscale inquiry convened in June 1977 and took evidence for 100 days, frcm proponents and opponents of the THORP plan; for details see The Plutonium Business. Press comments reinforced the opinion of many objectors that they had made a strong case against THORP, on technical, economic, environmental and political grounds. Nevertheless, when the judge's official findings were published, in March 1978, they discounted essentially every opposition argument, and accepted BNFL's case with only the most incidental reservation. The outcome of the Windscale inquiry drastically polarized nuclear controversy in Britain, and demonstrated the inadequacy of institutional avenues for input to official nuclear policy. Even Parliamentary procedures had to be put through hoops; to allow the House of Commons to debate the issue the government was compelled first formally to reject the THORP proposal, and then to reinstate it by means of a "special development order". The entire episode left even many nuclear supporters deeply uneasy.

Be that as it might, on 15 May 1978 THORP got the official green light. Throughout the years of controversy BNFL had insisted that the need for the plant was a matter of extreme urgency, that delay would seriously impede Britain's nuclear power program. In the event, BNFL was so preoccupied with sorting out the mess of its Magnox metal-fuel reprocessing, and so little advanced in its own planning, that it did not even apply for detailed "planning permission" for THORP from the relevant local authority until February 1983, nearly five years after receiving the government go-ahead. Even this permission was delayed for many weeks, since BNFL had yet to comply with agreements about local roads and other infrastructure developments linked to THORP. In the early stages of the Windscale controversy, in 1975-6, BNFL executives had talked of having THORP on stream by 1983. They were not even ready to pour concrete until 1984; the plant may - or may not - start up by 1990.

Cap la Hague

Whereas the British made the change in 1965 to reactors using oxide fuel, French plans to reprocess oxide fuel got off the ground later. The French were thus able to benefit from the expensive lessons learned by their precursors, especially the British, partners in United Reprocessors. That did not, however, entirely smooth the path for oxide fuel reprocessing in France. The French head end plant at Cap la Hague, called the Haute Activite Oxyde or HAO plant, was many months behind schedule when at last it started up in May 1976. The main union on the site took profound exception to what it considered management corner-cutting on safety, leading to strikes and dissension. The claimed capacity of the plant was 400 tonnes per year; but for several years after its start-up its annual throughput was far short of this. Like the operators of the Windscale Head End Plant, the operators of the Cap la Hague HAO plant for a time were proclaiming plans for its dramatic enlargement. In 1985, however, Cogema has already begun talking about shutting the HAO plant down permanently.

Reprocessing Stateside

In the US, official government policy from the 1950s onwards strove to transfer the responsibility - and the risks - of civil reprocessing to private industry. In the 1940s, of course, plutonium separation was an entirely military activity. More than one year before Enrico Fermi achieved the first self sustaining nuclear chain reaction, a few millionths of a gram of plutonium were separated from uranium that been irradiated at a university cyclotron. Two years later, primitive military reprocessing facilities were built in Hanford, Washington and Oak Ridge, Tennessee - from them came the plutonium that devastated Nagasaki, Japan on August 9, 1945. After the war, larger facilities were built in Hanford, Washington and Savannah River, South Carolina to extract military plutonium from nearby defense reactors. As these plants were being built, the US Atomic Energy Commission promised the first private reprocessor a long-term "base load" contract for military fuel to go with whatever commercial business could be found. In 1960, a consortium of three companies emerged with a proposal to build such a plant at West Valley, New York.

West Valley was completed in 1966 with a design capacity of 1,000 kilograms of fuel per day. The plant processed mainly low burnup military plutonium - averaging 2,000 megawatt-days per tonne - mixed with smaller amounts of commercial fuel at 25,000-30,000 megawatt-days per tonne. The plant was a commercial and technical disaster. Acid evaporators did not remove ruthenium and its decay product, rhodium, from the solvents used to dissolve incoming fuel. As the concentration of these insoluble metals increased in the "solvent," so too did personnel exposures, accidents, and costs. Average radiation doses to workers at the facility climbed from 2.7 rems per worker per year to more than 7 rem per year in 1971. The long-term government standard for personnel was 5 rems per lifetime, which meant that West Valley was "burning out" its workers. Many difficult operations were performed by temporary employees. Radioactive discharges into the nearby Cattaraugus Creek were several thousand times higher than expected, and levels of radiation four times the maximum permissible concentrations were found in Buttermilk Creek. At least one quarter, and possibly as much as forty percent, of the radioactive iodine that came in with spent fuel was released as a gas or liquid. The intensely radioactive fission products were stored in one of two carbon steel 750,000 gallon underground tanks built inside a concrete shell.

In February 1972, shortly after the five year government contract elapsed, the Atomic Energy Ccomission withdrew the plant's operating license, demanded a new earthquake design analysis, and construction of a new low level treatment plant to limit losses of strontium and cesium. The Commission also refused to allow storage of high level wastes in liquid form, which by that time totalled 600,000 gallons. By September 1976, the industry consortium announced its withdrawal from the reprocessing business, leaving the state of New York to care for the wastes.

Meanwhile other private reprocessors were taking on the challenging job of reprocessing commercial nuclear fuels. Two facilities were built, but neither has ever operated. General Electric's Midwest Fuel Recovery Plant at Morris, Illinois, never even started up; after two years of tests GE decided in July 1974 that it would not work, and abandoned it, writing off $65 million. Allied Chemical and Gulf Oil formed Allied General Nuclear Services to build the Barnwell Fuel Recovery Plant, at Barnwell, South Carolina. During its construction the cost of the plant itself soared; meanwhile licensing requirements grew progressively more stringent, and imposed the requirement for further facilities at the site. At length, in April 1977, President Jimmy Carter withdrew official support for the Barnwell plant, as a key feature of his new policy for control of nuclear weapons proliferation (for details, see The Plutonium Business).

A Government Takeover of Barnwell?

In 1980-81, the Reagan administration made valiant efforts to turn the fallen Barnwell commercial reprocessing plant into a "civilitary" facility. Initially the Energy Department proposed to buy Barnwell outright and use it to extract military plutonium frcm commercial fuel, turning reactors into defacto military facilities. That encountered insuperable political objections. So the Department had two choices. It could offer to buy all the plutonium produced by the plant for "research" purposes, thereby making existing research plutonium available for military purposes. Or it could find some new owners.

The first stumbling block was the plant itself. In a private report to the Energy Department, Argonne National Laboratories reported in December 1980 that Barnwell could not comply with occupational or environmental radiation standards without more than $1 billion in new capital investment. Argonne's report concluded that the plant was built during a time when reprocessing was viewed as a highly competitive enterprise, with contracts sought in the range of $20-50 per kilogram. (Current prices are above $800/kg.) This led, in their view, to minimal personnel shielding, very limited capacity for remote control or maintenance, low earthquake design standards, a "barely marginal" system for keeping track of fissionable liquid plutonium as it moved through the system, and no way to control emissions of many radioactive gases.

In its unusually candid assessment, Argonne told the department that the Barnwell "design and construction is unfortunately no better than that of the NFS plant (West Valley) in the event of mishaps in the liquid handling parts. Solid piping and welding, with inadequate space within the cells, complicates (or makes impossible) reasonable modes of recovery from severe contamination or damage events . . . . full scale operation would be accompanied from the moment of startup by somewhat inordinately high operation and maintenance (outage time and cost) risks . . . . These potential operation problems, combined with the licensing problem described above, are of sufficient magnitude that independent groups which have reviewed the BFRP [Barnwell Fuel Recovery Plant] are fearful that it could suffer the same fate as NFS' West Valley plant and give the industry a further black eye. Specifically, they fear that the first serious contamination in the liquid section of the facility might require that the entire plant be written off from further fuel reprocessing, and perhaps other uses as well."

This grim report did not however dissuade the Energy Department from seeking new private sector owners for Barnwell. It found an anxious participant in a consortium of German utilities. The German utilities expressed an interest in owning a 10-25 percent share of Barnwell, financing half the needed capital improvements, and using at least half the plant's total capacity for ten years. The US construction firm Bechtel also expressed some interest in operating Barnwell. The Energy Department proposed a combination of federal loan guarantees and an iron-clad contract to purchase all the plutonium that could be produced by the plant whether it was shut down or operable, whether the plutonium was needed or not. At length, this proposal proved unacceptable to Congress, Allied General Nuclear Services, Bechtel, and the German utility consortium, and irrelevant to the utilities. Faced with all this, Allied General Nuclear Services have begun to scrap it and sell off reusable components, intending to write it off as a tax loss. The prospect for any further involvement of either private risk capital or government money in civil reprocessing in the US seems remote, if not nonexistent.

WAK and Gorleben

In Federal Germany there was of course no nuclear weapons program to establish a commitment to reprocessing, nor to finance the first reprocessing plants. The Federal government nuclear laboratory at Karlsruhe had built a pilot-scale reprocessing unit, designated WAK, with a nominal capacity of 40 tonnes per year. Nevertheless, the Federal Ministry for Research and Technology had decreed by 1969 a policy embracing reprocessing of German oxide fuel; reuse of the recovered plutonium in so-called "mixed oxide" fuel for conventional nuclear power plants, manufactured at the site of the reprocessing plant; and storage and disposal of all the resulting wastes at the same site, in an underground repository for low-, medium- and high-level wastes. This integrated facility was to be known by an invented German word of jaw-breaking unwieldiness: it would be an "Entsorgungszentrum".

The plan was initially adopted by a consortium of four German chemical companies. By 1974, however, they had reassessed its economic prospects and had second thoughts. When they abruptly dropped their reprocessing plans they also dropped the German utilities into a legal and regulatory soup. The German "Atomgesetz" or atomic law made licensing a power plant conditional on provision for the management and disposal of spent fuel from the plant. Because official policy had always, as elsewhere, assumed reprocessing to be a necessary corollary of such arrangements, the sudden disappearance of the only German plan for a reprocessing plant caused consternation in utility boardrooms. The utilities soon realized that they had no option but to set up their own reprocessing company. In due course it emerged: the Deutsche Gesellschaft fuer Wieder-aufarbeitung von abgebrannten Kernbrennstoffen - DWK, pronounced "dayvaykah".

The Federal Ministry was still touting its "Entsorgungszentrum" - with no abbreviation. The reprocessing plant at the "Entsorgungszentrum", however, was to be nearly 40 times of WAK, an awesome scale-up. In early 1976, after convoluted political maneuvers (see The Plutonium Business), the Premier of Lower Saxony, Ernst Albrecht, reluctantly offered a site in a remote corner of his province, near a village called Gorleben, only five kilometers from the Elbe River, on the far side of which were the fences and gun-turrets of the German Democratic Republic. The Ministry at once accepted. The proposal triggered bitter local opposition; in response to it Albrecht commissioned a panel of foreign nuclear experts to prepare an independent assessment. The report from the Gorleben International Review was presented and defended by its authors in a week of hearings in Hannover. By a bizarre twist the hearings opened on the morning of March 28, 1979, thus coinciding virtually to the instant with the beginning of the accident at Three Mile Island. Six weeks later Albrecht announced on national television that the proposal for a reprocessing plant at Gorleben was "politically unacceptable".

The decision threw the German nuclear power program into fresh convulsions. Some German utilities already had reprocessing contracts with BNFL and Cogema; but the contracts covered only a modest fraction of the total quantities of spent fuel that their power plants would be discharging. Cooling ponds at certain older German nuclear plants were already becoming uncomfortably full of fuel. One corollary of Albrecht's Gorleben decision was the tacit abandonment of the original Ministry plan for a single vast "Zentrum," with a single enormous reprocessing plant. The plant proposed for Gorleben had been intended to have an annual capacity of 1400 tonnes per year. In the months that followed Albrecht's decision, however, DWK let it be known that it would settle for a plant capacity of perhaps 350 tonnes per year. It would, on the other hand, be seeking to build more than one plant. One possible site after another, in one province after another, was mentioned only to be set aside, invariably in the wake of local outcry. The issue split Federal and provincial politicians and parties; by the early 1980s there was no longer any pretense that it was purely a technical decision and above party politics.

Reprocessing Plants 1985

In 1985 there are in all only five operating reprocessing plants known to accept spent fuel from commercial power reactors:

- the B205 plant at Sellafield in Britain;
- the UP-1 plant at Marcoule and the UP-2 plant at Cap la Hague in France;
- the Tokai Mura plant in Japan;
- the Tarapur plant in India.

There is also believed to be an operating plant in the Soviet Union, probably in the nuclear complex near Chelyabinsk in the south Ural mountains. Like the British B205 plant and the two French plants, the Soviet plant is dual-purpose, in that it separates plutoniun not only for civil purposes but also for weapons. Reprocessing plants now under construction include:

- the Thermal Oxide Reprocessing Plant at Sellafield (formerly Windscale) in Britain;
- the UP-2/800 and UP-3 plants at Cap la Hague in France;
- the Ezeiza plant in Argentina;
-the Chashma plant in Pakistan;
- the Resende plant in Brazil; and
- the revamped Trombay plant and the new Kalpakkam plant in India.

Spent fuel due for eventual reprocessing in the British and French plants is already stored in the cooling ponds at Sellafield and Cap la Hague, with further shipments arriving regularly.

In addition to these plants there are six others variously shut down or otherwise out of service:

- the B204 Head End Plant in Britain;
- the Nuclear Fuel Services plant at West Valley, New York, in the US;
- the Midwest Fuel Recovery Plant at Morris, Illinois, in the US;
- the Barnwell Fuel Recovery Plant in South Carolina, in the US;
- the Eurochemic plant at Mol, belgim;

Four experimental reprocessing plants are in operation in 1985:

- the fast breeder fuel reprocessing plant at Dounreay in Britain;
- the WAK plant at Karlsruhe in Federal Germany;
- the SAP and TOR fast breeder reprocessing plants in France.

Reprocessing plants whose existence can only be inferred, and whose status is clearly ambiguous, include those believed to be in Israel and China, and possibly in South Africa. If these plants do indeed exist - as some intelligence reports strongly indicate - their role is almost certainly in connection with nuclear weapons development in the countries named. We shall return to the qaestion of reprocessing in the Third World in Chapter 6.

Consider, then, the four countries now actively involved in reprocessing of civil spent fuel: Britain, France, Federal Germany and Japan. Britain's commercial reprocessing facilities are operated by British Nuclear Fuels p1c, still known by its old acronym of BNFL. BNFL was "hived off" from the UK Atomic Energy Authority by an Act of Parliament in 1971. The intention was for it to become a "cornmercial" company, doing business by normal conmercial criteria. In fact 100 percent of the shares of BNFL were owned by the AEA - and thus indirectly by the British government. The same arrangement is still in effect in 1985. The present Conservative government of Margaret Thatcher announced plans in 1983 to put shares of BNFL on the market to private investors; but these plans for so-called "privatization" of the company have since been postponed, not least because of unfavorable publicity about a discharge of radioactive material fran the company's Sellafield site in October 1983. The discharge of highly active solvent into the Irish Sea was contrary to the terms of BNFL's operating license; in consequence the company was sent for trial on criminal charges in June 1985. It was found guilty on two counts and fined £10,000.

BNFL has spent most of the past decade rectifying a major problem with reprocessing of Magnox metal fuel at Windscale and Sellafield. In 1976 it received government approval for new capital investment to "refurbish" the Magnox facilities, at a cost then estimated at £245million. The "refurbishment" in due course proved to entail construction of a complete new Magnox fuel reception and "decanning" - fuel rod stripping - facility, called Pond 5, that became much the largest single building on the Sellafield site. In addition to the Pond 5 complex BNFL is also now completing construction of the SIXEP site ion exchange plant, a water-treatment plant intended to reduce the amount of radioactivity in the waste liquid that is discharged offshore into the Irish Sea. This offshore discharge is one of BNFL's most controversial activities. The company has announced plans for further waste-treatment facilities costing some £150 million, while insisting that they are unnecessary and a misuse of investment.

A corollary of these large-scale investments in clean-up facilities is the continuing dispute between BNFL and its largest single customer, Britain's Central Electricity Generating Board. All the recent expenditure on extra Magnox processing and waste-treatment has incurred massive costs even by nuclear investment standards. The CEGB, however, signed long-term contracts in the 1960s to cover reprocessing of fuel from its Magnox reactors essentially throughout their operating lives. The terms of these contracts have long since become far out of line with the actual cost to BNFL of providing the Magnox reprocessing, and cleaning up after it. Accordingly, BNFL has been trying for more than a decade to get the CEGB to renegotiate the Magnox contracts, and - of course - to agree to pay a price more in keeping with the true cost of the service. The CEGB is understandably unwilling to redraft contracts that are now so advantageous to it. As a result BNFL's auditors have for some years included a terse qualification in the notes to BNFL's annual financial statement, noting the possible contingent liabilities associated with the long-term Magnox reprocessing contracts. How much BNFL is losing on Magnox reprocessing remains a corporate secret; but it is bound to be a tidy sum. The CEGB's recent decision to extend the anticipated working lives of the Magnox stations from 25 years to 30 will presumably add a further twist to the tale. How this will affect the Magnox reprocessing situation has yet to be explained. Both BNFL and the CEGB remain acutely close-mouthed about the details.

Nor is Magnox reprocessing the only source of friction between the two organizations.When in the mid-1970s BNFL revealed plans for new oxide reprocessing facilities at Windscale, the original proposal focussed on reprocessing for foreign customers, in particular the Japanese utilities. As public controversy boiled over, BNFL redirected the emphasis of its argument, insisting that the proposed new oxide reprocessing plant would be essential to service Britain's own advanced gas-cooled reactor (AGR) power plants, all but one of which were owned and operated by the CEGB. These power plants were to be sure far behind schedule; in due course, nevertheless, they would begin to discharge spent oxide fuel for which reprocessing would be required. So, at least, ran the BNFL argument; and at length it was accepted by the Inspector's report on the Windscale inquiry, published in March 1978. The proposed Thermal Oxide Reprocessing Plant - THORP - received the official go-ahead on 15 May 1978; and soon thereafter BNFL obtained signatures from the Japanese and other foreign clients on contracts for THORP's services.

During the Windscale Inquiry the lop-sided nature of these contracts had already been coyly and reluctantly revealed. The customer agreed to pay - in advance - the estimated cost of constructing his pro rata share of the plant, plus a profit believed to be an additional 25 per cent. In return for this payment the customer received no guarantee that this spent fuel would be reprocessed, nor that any of his money would be returned were it not. If THORP did not work BNFL could simply return the spent fuel, and pocket the money.

The willingness of customers to sign a contract on such terms struck some observers as evidence of the urgent desire merely to get the spent fuel out of the utility cooling-ponds with no concern for what happened to it thereafter. The CEGB, however, proved not to be quite so breathlessly eager as the foreign customers to deliver itself to BNFL bound hand and foot. The CEGB's experience with BNFL and Magnox reprocessing probably reinforced its lack of enthusiasm for BNFL's proposed contract terms for oxide reprocessing.

As the months and years passed, BNFL and the CEGB remained locked in stalemate over the terms for reprocessing AGR oxide fuel in THORP. In public both organizations behaved as though the issue had already been resolved - that AGR fuel would indeed be reprocessed in THORP, and that the delay in reaching a contractual agreement was merely an incidental detail that would be tidied up when the time came. In 1985, nevertheless, the AGR reprocessing contract remains unsigned.

During the controversy of 1976-7 about whether permission should be given for THORP, BNFL took the position that the plant was needed urgently - that delays might seriously affect Britain's domestic nuclear program. Once the official go-ahead was given, however, the alleged urgency somehow dramatically abated. BNFL did not even apply for detailed "planning permission" from the local council until February 1983. When it did apply, the permission was withheld for many weeks, since BNFL had yet to comply with its earlier undertakings about local infrastructure effects - roads and the like. The contracts for civil engineering were not even put out to tender until later in 1983. Site work on THORP began in 1984 - despite BNFL's claim in the mid 1970s that the plant would be on stream by 1983. The plant is not now expected to be completed until 1990.

Its estimted cost has varied widely over the years; the most recent estimates put the capital cost at some £1.8 billion, about 50 percent higher than the cost estimated at the time when foreign customers were signing their cost-plus contracts in the later 1970s and early 1980s. In December 1983 it was reported that BNFL had unilaterally informed its customers that the cost to them was to be some 30 per cent higher than originally agreed. The customers were far from pleased; one unidentified customer that had signed a contract earlier in 1983 was quoted as saying that if it had known of the impending cost-increase it would not have signed. Nevertheless BNFL declared that THORP was fully booked for the first ten years of its life, and would be seeking contracts for operations thereafter. Whether this "full booking" did or did not include reprocessing of AGR fuel for the CEGB and the much smaller South of Scotland Electricity Board was not made clear. If the "full booking" does - as seems probable - include the domestic spent fuel, it is slightly premature to claim that it is "booked," in the absence of a signed contract. On the other hand, if BNFL has indeed filled THORP to capacity without setting aside space for the British utilities, there will certainly be spectacular recriminations in the offing.

There are a number of parallels between the British reprocessing story and that of France. As described above British Nuclear Fuels was separated off from the government Atomic Energy Authority in 1971 by Act of Parliament, to became a quasi-commercial fuel service company - albeit wholly-owned by the AEA. In the same way the French government in 1976 separated off the nuclear fuel activities of the official Commissariat a l'Energie Atomique (CEA), and reconstituted them in similar quasi-commercial form as the Compagnie Generale des Matieres Nucleaires - always known as Cogema. Cogema, however, was in turn fully owned by the CEA. Among the corporate responsibilities assigned to the new body was that for reprocessing. Cogema took over the facilities at Marcoule and Cap la Hague. It also took the place of the CEA in the three-way partnership called United Reprocessors.

Like Britain, France had moved from an initial nuclear power program based on metal-fueled reactors to a second program based on reactors using oxide fuel - in the case of France, pressurized-water reactors. Like the AEA, the CEA assumed that oxide fuel would have to be reprocessed; and like the AEA the CEA embarked on oxide reprocessing by adding a "head end" plant to its metal-fuel separation plant. The French head end plant, called HAO (for Haute Activite Oxyde) was added to UP-2 at Cap la Hague; it came into service in 1976, a few months after the creation of Cogema. It at once presented the Cogema management with problems. The main union on the site, the Confederation Francaise du Travail (CFDT), claimed that the design of the HAO was seriously inadequate, and would cause undue risks to workers. Almost as soon as the plant had processed its first batch of oxide fuel it was hit by a strike that lasted for many weeks. The labour unrest set a pattern that was to continue.

Like the Head End plant at Windscale the HAO plant at Cap la Hague had to take its turn, remaining out of use while the main separation plant was dealing with metal fuel. For this reason, and also because of various technical troubles arising from its design, the HAO plant, like the Head End plant, actually processed a much lower throughput of fuel than its nominal capacity of 400 tonnes per year - only 250 tonnes total from 1976-1982, then 250 tonnes in both 1983 and 1984. Be that as it might, Cogema had ambitious plans both for HAO itself and for oxide reprocessing in general - much like the plans of BNFL. In the late 1970s, while the Windscale controversy was clouding the issue in Britain, Cogema was planning three new oxide reprocessing plants. One would be a doubling of the HAO to 800 tonnes per year, called UP-2/800; the other two would be new 800-tonne plants dedicated entirely to oxide fuel, and designated UP-3A and UP-3B. One of these latter plants would be financed wholly by prepayments from foreign customers; the other would include a significant component of such foreign business.

Unfortunately for Cogema's expectations, however, these plans underwent drastic revision, both as to timetable and as to scale (for details see The Plutonium Business). By 1985 the two new 800-tonne plants had become one single plant, called UP-3, dedicated to and completely paid for - in the amount of 28 billion French francs - by foreign clients. It was not actually expected to start up until 1989. The doubled HAO, UP-2/800, was still being built, to a much-delayed schedule; its eventual start-up in 1992 would be accompanied by the permanent shutdown of the original HAO after only about a decade of mostly below-capacity operation. It has always been acutely difficult to ascertain the true financial circumstances of French nuclear activities; this obscurity applies in spades to reprocessing, both for Electricite de France and for Cogema's foreign customers.

As Irvin Bupp and Jean-Claude Derian have described, "La Hague . . . buys time for both France and for Cogema's foreign customers to continue the construction of light water reactors . . . It is important to understand the nature of the real bargain between Cogema and the governments of Japan, West Germany, Sweden, Switzerland, the Netherlands, and Italy. In effect, these governments are giving Cogema front-end capital and accepting an apparently open-ended, longer-term financial risk in return for a five to ten year grace period within which to launch their own nuclear programs while claiming that progress is being made on the politically volatile issue of radioactive waste disposal . . . the mere activities of reprocessing and vitrification can be used to demonstrate progress, as opposed to indecision and stagnation."

The bargain between La Hague and its foreign customers will last only a few years. After these contracts are fulfilled, Cogema expects an enormous surplus of reprocessing capacity - equal to about 50 metric tons of separated plutonium by the year 2000. Electricite de France is far from eager to soak up this surplus; as we described in chapter 2, the utility is willing to buy only a very limited quantity of plutonium fuel from Cogema at a price that is probably below Cogema's internal cost. Nor is there enough planned breeder capacity to save plutonium for. So where will Cogema turn to earn a return off its huge investments in reprocessing? One answer could be found in a worrisome deal arranged in fall 1984 with the Belgian nuclear manufacturing firm of Belgonucleaire. These two firms announced their intention to jointly market plutonium fuels to international buyers beginning in the late 1980s. Who, one might ask, would be interested in paying a substantial premium for a fuel that is no better at generating electricity than natural uranium?

Several of Cogema's immediate customers are to be found in Federal Germany. Unlike the goverment-owned electricity suppliers of Britain and France, Federal German utilities are privately-owned, and serve individual areas of the country, rather like the utilities of the US. In the mid-1970s the German utilities realized, as described above, that no other German company was going to accept their spent fuel. In consequence the thirteen German utilities banded together to set up their own reprocessing company, DWK. After more than a decade, and the vicissitudes described above, DWK had run through at least a half-dozen possible locations for reprocessing plants; it had yet to get any farther than preliminary proposals for a plant of 350 tonnes annual capacity. In 1984 the choice narrowed down to two sites. One, Dragahn, was only some 30 kilometres from Gorleben. It had been put forward, unexpectedly, in 1983, by Lower Saxony Premier Ernst Albrecht - the same politician who had turned down the original Gorleben "Zentrum" four years before. The other site was at Wackersdorf, in Bavaria, the power-base of the controversial right-wing political boss Franz Josef Strauss, who was an enthusiastic supporter of the proposal. In January 1985 the German cabinet decided to give priority to reprocessing over direct disposal of spent fuel and, one month later, a meeting of the DWK board opted for Wackersdorf. Local feeling around Wackersdorf was, however, by no means so enthusiastic. German planning procedure requires approval by several official bodies; there will also be a formal inquiry.

If in due course the 350-tonne plant is indeed built at Wackersdorf, it is unlikely to come into operation before the mid-1990s. A contract for construction has been tendered to a consortium of German companies led by Kraftwork Union, the reactor vendor, at an estimated cost of 5.2 billion DM, not including cost increases during construction, interest, taxes, or the cost of the site itself: much higher than the DM 6-12 billion estimated during the Gorleben hearings for a facility four times the size. Ironically, the decision to favor reprocessing came after a $16 million research program had concluded that spent fuel could be disposed of as safely in salt formations as reprocessed fuel with a 30 percent savings in nuclear fuel and waste costs. Accordingly, the German utilities are already taking other measures to cope with their backlog of spent fuel - including measures that do not involve immediate reprocessing. They will be discussed in Chapter 4.

Like the German utilities, the nine Japanese utilities, too, had to make their own collective arrangements for dealing with spent nuclear fuel. They adopted a "double track" approach. Their joint Enrichnent and Reprocessing Group contracted to deliver some of their spent fuel halfway around the world to Windscale and Cap la Hague, for reprocessing by BNFL and Cogema - on the one-sided terms mentioned above. At the same time the Japanese utilities supported the construction of a pilot-scale reprocessing plant at Tokai Mura although it was actually built and financed by the government Power Reactor and Nuclear Fuel Corporation (PNC). The Tokai Mura plant ran into every kind of difficulty, from purely technical to diplomatic; for details see The Plutonium Business.

Japanese nuclear officials and executives talked for many years about moving on to a larger, commercial-scale plant. The problem, as was so often the case, centred on finances. At length, nevertheless, the renamed Japan Nuclear Fuel Corporation announced in mid-1984 that a new nuclear fuel processing complex was to be set up at Shomokita, at the northern end of Honshu island. Facilities to be constructed would include a gas-centrifuge uranium enrichment plant and a reprocessing plant, whose capacity would be 1000 tonnes per year. The reprocessing plant was expected to come into service by 1993.

In all, then, there are in 1985 a total of five commercial-scale oxide fuel reprocessing plants actually under construction or at an advanced planning stage: one each in Britain, Federal Germany and Japan and two in France. Their total design capacity - allowing for the wide variation in interpretation of this concept - is intended to be about 4000 tonnes of spent thermal oxide fuel per year. In very rough terms, allowing for a discharge of perhaps 30 tonnes of spent fuel frcm a 1-GW power plant per year, this reprocessing capacity would be able to handle the output from perhaps 130 large nuclear plants. By the mid-1990s however, despite the near-standstill of new nuclear plant construction, there will be well over twice that amount of nuclear power in operation worldwide. What is to become of all that spent fuel? We shall consider this crucially important question in Chapter 4.

Chapter Four

Alternatives for Spent Fuel Management

Electricity suppliers want the heat that can be generated by a chain reaction. Unlike bomb-makers, electrical utilities do not especially care about the constitution of the material left after the chain reaction stops. For the utilities the overriding consideration is that for technical reasons they can no longer extract further heat from the fuel: as a fuel it is "spent." This spent fuel must be removed from a power reactor and replaced with fresh fuel capable of supporting an efficient chain reaction.

In the early years of civil nuclear power the utilities, it is true, harbored one strong impression. The scientists in the national nuclear organizations had assured the utilities that the spent fuel contained very valuable materials: unused uranium and newly-created plutonium. In Britain, for example, the economic analyses of the competitive status of the civil Magnox stations depended almost entirely on a so-called "plutonium credit" attributed to the spent fuel. According to the UK Atomic Energy Authority this civil spent fuel would itself be worth a great deal to the Central Electricity Generating Board, by virtue of the plutoniun in it. The plutonium would be extracted by reprocessing at Windscale, and set aside with the CEGB's name on it, ready to use in manufacturing fresh fuel. Furthermore the fresh plutonium fuel would be used, not in an ordinary Magnox reactor, but in the AEA's special favorite: a "fast breeder," soon to make conventional reactors obsolete. The fast breeder would produce even more plutonium than it burned, and the original spent fuel would have endlessly powerful offspring. Such at least was the story in the late 1950s and 1960s, not only in Britain but also in the US and most other nuclear industrial countries. As a consequence, electrical utilities were persuaded to believe that their spent fuel was not a burden but a boon.

In the 1980s they know different. As earlier Chapters have indicated, the anticipated plutonium bonanza has receded like the desert horizon. No longer do utilities expect anyone to pay them for their spent fuel. On the contrary, as indicated in the preceding Chapter, utilities have long since had to pay open-ended prices on punitive terms just to get rid of their spent fuel - even if only temporarily. Worse than that, some utilities have simply been unable either to find or to afford a way to get rid of their spent fuel. Accordingly, throughout the past decade, an entire new philosophy of spent fuel management has had to be created, to cope with the growing inventories of spent fuel that now lie heavy on utility hands.

Almost every nuclear power station currently in operation has a water-filled basin called a "cooling pond". When spent fuel has been removed from the reactor it is deposited in this cooling pond. The water in the pond serves not only to carry away the residual heat generated by the radioactive fission products in the spent fuel, but also acts as shielding to protect the plant staff from the penetrating radiation emitted by the fission products. The basic engineering premise of the cooling pond is sound enough; but in practice it has certain drawbacks.

The first is the most obvious, and for many utilities the most pressing. Spent fuel is heavy; a single PWR fuel element may weigh 800 kilograms. A cooling pond is no simple swimming pool, but a massive structure of thick concrete; nevertheless there is a limit to how much mass of fuel it can support. Until the past decade, nuclear power plant operators have always proceeded on the assumption that spent fuel would be removed from the cooling pond in five years or less, to be shipped to a reprocessing plant. Cooling ponds have been sized accordingly, to accommodate perhaps three full reactor-core's worth of spent fuel. In practice even this limited capacity is not fully available; in many places regulatory requirements stipulate that a power-plant pond should keep enough space free to accept a full core in case of emergency.

The original design concept for a cooling pond assumed that the spent fuel would be stacked in the water more or less as the fuel emerged from the power plant. At the British and French first-generation gas-cooled nuclear plants the individual rods of spent metal fuel are simply laid in open baskets underwater. The more elaborate and much heavier oxide fuel elements of water-cooled reactors, PWRs and BWRs, are lowered into supporting racks in the pond. Neither of these straightforward, not to say rudimentary, arrangements is satisfactory if fuel is to remain in the pond for very long.

The severest constraint arises for the British and French gas-cooled metal fuel. This fuel is clad in a magnesium alloy that is very efficient in a chain reaction, and gives adequate protection to bare fuel in the carbon dioxide environment of a gas-cooled reactor, but corrodes rapidly in water. Fuel with this cladding cannot be left safety in water for more than about a year, before the cladding begins to deteriorate and release radioactivity into the pond-water. When the intention was to reprocess the fuel as soon as it was cool enough not to damage the solvents, the deterioration of the cladding presented no problem. Any unexpected delay in reprocessing, however, would lead to trouble. Such a delay did indeed arise at Windscale in Britain in 1972-3; see The Plutonium Business for details. The bottleneck created by this interruption of Magnox reprocessing in turn led to a build-up of old spent fuel, in degenerating condition, that eventually necessitated construction of a new "decanning" facility, ponds and all, costing more than £300 million. There is, however, a different approach to managing the spent metal fuel from gas-cooled reactors, that avoids essentially completely the problem of cladding corrosion. It will be described later in this Chapter.

Oxide fuel, whether water-cooled or gas-cooled, is much more durable than metal fuel, and less susceptible to corrosion. These effects do to be sure arise; but the initial problem for operators of plants using oxide fuel is simple shortage of pond-storage capacity. The ponds at most commercial nuclear plants were not sized nor engineered to acconmodate open-ended quantities of spent fuel. Although the fuel itself caused no major difficulties, there was not enough room for it.

Various options suggested themselves, and one in particular was adopted almost immediately in the US, Federal Germany and other countries where utilities were facing a growing backlog of spent fuel with no early prospect of getting rid of it. By inserting specially-engineered racks, sometimes made of boron steel to prevent accidental criticality, utilities were able to pack spent fuel much more closely together in cooling ponds, gaining several years of available storage capacity. This technique is called "reracking".

At one especially well-studied US plant - the Tennessee Valley Authority's two-unit Sequoyah station - the spent fuel storage pool was designed and licensed to accommodate about three years' worth of discharged fuel with space left over to store a full core in the case that an accident required its removal. This contingency is called "full core reserve," and is strongly advised by the Nuclear Regulatory Conmission. Reracking more than trebled the storage capacity of the Sequoyah pool to handle more than nine years of discharges, still allowing for a full core to be promptly unloaded. A second re-rack, using stainless steel racks with radiation-absorbing boron cores, recently gave TVA enough breathing space for nearly nineteen years of spent fuel. This is where the Sequoyah plant stands today, having increased its onsite spent fuel storage capacity nearly ten times without building a new pool or shipping spent fuel for reprocessing or final disposal.

Reracking was the first technique to be licensed by the Nuclear Regulatory Commission as a way to relieve the pressure on utility cooling ponds. At first, the Commission did not permit the utilities to take credit in their calculations of pool capacity for the lower heat generation of aging fuel. But "burnup-credit racks" - which allow still tighter packing - are coming into use. TVA's spent fuel management group is planning to install these racks, increasing the storage capacity of the Sequoyah pool to nearly the life of the reactor - 27 years' worth of discharges. Rod consolidation, which involves the removal of the metal frames - sometimes called skeletons - that hold the rods would double the capacity to roughly 60 years, far beyond the estimated lifetime of the reactors themselves. These more sophisticated options will be discussed in more detail later in Chapter 4.

Certain utilities also had another comparatively simple option available. Ponds at their newer plants contained relatively low inventories of spent fuel. It was therefore possible to ship spent fuel from the crowded ponds at their older plants for storage in the newer ponds. This so-called "transshipment" of course required special shipping containers that would protect the spent fuel elements themselves, and also shield those nearby from the intense radiation given off by the spent fuel inside. Such "shipping casks" had of course been in use in any case, for the shipment of spent fuel from power plants to reprocessing plants. Once it became apparent that they might also be of use for transshipment between power plants to ease pond crowding, a further possibility at once suggested itself. If fuel were to be loaded into a cask merely to increase a utility's storage capacity, could the fuel not simply be left in the cask itself for storage? If it were safe to ship the cask from one plant to another, surely it ought to be safe just to leave the cask where it was, filled with spent fuel.

Reracking and cask storage were the first manifestations of what was to become a full-fledged new nuclear discipline - "spent fuel management". Until the late 1970s, utilities almost everywhere had scarcely given thought to the possible options available for "managing" spent fuel. They had taken for granted that the "back end of the fuel cycle" was predefined and unique: you shipped your spent fuel to a reprocessing plant and forgot about it. You might, to be sure, anticipate in due course using the recovered uranium and plutonium from reprocessing, but that was incidental. The important thing was to shift the spent fuel, and the responsibility for it, to someone somewhere else. When at length it became beyond dispute that the utilities themselves would have to continue to watch over the mounting inventories of spent fuel they were creating, spent fuel become a management problem. Fortunately for the utilities, once it had been thus identified, the problem appeared to have a significant range of potential solutions, at least in the short and medium term. Reracking and cask storage were only two of them; others rapidly materialized, in various countries and circumstances.

In Federal Germany casks had been used in quantity for many years for spent fuel transport. A design had evolved, based on cast modular iron, that was cheap enough to be used not only for transport but also for storage. In May 1979, as described earlier, the Lower Saxony government turned down the proposal for a reprocessing plant at Gorleben. The German utilities and their official supporters thereafter at once adopted cask storage as an element of policy, making a virtue out of necessity. The utilities, through their joint company DWK, together with the German engineering firm of STEAG, embarked on an urgent program to develop suitable casks that could be licensed not only for transport but also for dry storage of spent oxide fuel. The main contractor was the German firm GNS. In 1980 the GNS design of dry storage casks, called CASTOR, first gained certification under the relevant IAEA criteria as applied by the German regulatory bodies.

CASTOR casks were subjected to every variety of indignity - drops, crashes, fires - and satisfied the safety requirements stipulated by the German authorities. In 1981 the first CASTOR casks were loaded with spent fuel at the Wuergassen station, to commence a demonstration program for dry storage. Sixteen BWR fuel elements that had been in the Wuergassen cooling pond about a year were loaded into the heavily-instrumented cask in the pond; the cask was then filled with inert cover gas. Subsequent monitoring was reported to have revealed no fuel damage even at temperatures of

400 degrees Centigrade, 25 degrees higher than the maximum permitted by US regulatory authorities. Similar demonstrations were then undertaken with different types of fuel. Meanwhile the German firm Transnuclear, previously specializing - as its name implies - in nuclear transport, was developing a whole range of designs of storage cask, the TN series, to suit the various types and sizes of fuel from German commercial and experimental reactors.

As investigations continued on the loading, handling and monitoring of storage casks themselves, work was proceeding on installations at which to store the loaded casks. By an ironic twist, the first of these dry spent-fuel stores was built on the site at Gorleben that had originally been earmarked for a reprocessing plant. The construction license for the Gorleben dry store was issued in June 1981 and construction was completed in 1985. The first spent fuel was slated to arrive early this year, but an Administrative Court in Luneberg ruled, in a further ironic twist, that the facility does not meet the terms of the German Atomgesetz. At this point it is unclear whether a reprocessing plant at Gorleben would either; a final decision by the federal Supreme Court is expected by early 1986.

The proposed Gorleben dry store is essentially a vast concrete vault designed to accommodate up to 1500 tonnes of spent fuel. Sealed cylindrical storage casks filled with spent fuel stand on their ends in serried ranks, in a total of 420 positions on the floor of the vault. The walls and roof of the vault are lined with ventilation openings to foster convective circulation of air to remove residual heat from the casks. The casks themselves provide essentially all the requisite containment and shielding for the spent fuel; they also thus represent the main capital investment involved. The building is relatively simple, and relatively cheap. A similar facility to house up to 1500 tonnes of spent fuel is being built at Ahaus; it, too, has been delayed in court over a zoning issue. To date research has turned up no instances of cladding failure in monitored dry cask storage.

Dry storage of spent fuel in specially-modified transport casks is an option now under study also by utilities in the US. As yet such interim storage is not formally licensed by the Nuclear Regulatory Commission; but a decision by the NRC is awaited shortly, and is expected to be favorable. Both Virginia Electric Power Company and Carolina Power and Light have GNS casks loaded with small quantities of spent fuel for on-site dry storage at their nuclear units. At the moment, the debate on spent fuel management is not over reprocessing, but over in which order one should choose the following alternatives: burnup-credit racks, rod consolidation, new on-site pool construction, or dry storage in one of several competing modes. The costs for all these options are far below those of reprocessing.

Another spent-fuel management measure under study in the US would also win utilities further room to maneuver, whether they opted for reracking or for dry storage in casks. Called "fuel consolidation," it consists of partially dismantling the complex fuel elements of water-cooled reactors: removing the ends and supporting grids, leaving just the fuel pins themselves. These individual fuel pins, low in fissile content and requiring much less surface-contact with fast-moving coolant, can be bundled closely together. When thus consolidated, spent fuel pins can be "bottled" in metal canisters and returned to the cooling pond, packing the equivalent of well over twice as much spent fuel into a given volume of pond. Alternatively - for instance if the pond cannot support the additional weight of consolidated fuel - the fuel pins can be similarly packed into storage casks, with much more fuel per cask - saving both on the cost of casks and on the cost of somewhere to store the casks themselves.

Fuel consolidation is in the development stage, but may not remain so for long. Already, Westinghouse has consolidated four nuclear fuel assemblies for Duke Power in the southeast United

States, squeezing these rods into about one-sixth the space that they would use in high-density fuel storage racks. There is some question over whether consolidation would even require NRC licensing.

Taking again the example of TVA's Sequoyah plant, fuel consolidation would expand the storage capacity of the original pond to more than thirty times its design capacity, without the capital expense and licensing process for building a new pool or the hazards of transporting the fuel to a new location. However, rod consolidation raises some safety questions: for instance, of potential worker-exposure during the consolidation operation itself, and of criticality-safety. Storage for the much less radioactive, but still dangerous, skeletons must be arranged. Nevertheless some analysts consider that fuel consolidation will become standard practice for operators of water-cooled reactors. It will almost certainly be necessary at some stage in the event that spent fuel itself is to be the basis for final disposal. The implications of this will be discussed in Chapter 5.

Unlike the other countries heretofore mentioned, Canada has always had a policy not of reprocessing but of storing the spent natural uranium oxide fuel from its power reactors. The clusters of CANDU reactors at the five commercial nuclear power plants in Ontario, Quebec and New Brunswick were provided during the construction stage with cooling ponds on a much larger scale than those specified in the US and Europe. The small fuel "bundles" discharged from a CANDU travel a shielded route into the cooling pond, there to remain - at the moment - indefinitely. Some of the spent CANDU fuel in the ponds at the Pickering plant near Toronto is now well into its second decade of residence in the ponds on the site. The pond-water chemistry must be tightly controlled; but no problems of fuel-cladding corrosion have been reported.

Canada has also been developing for many years a distinctive concept for spent fuel storage on a longer-term basis. On the assumption that spent fuel now in power plant ponds will eventually be better stored in a less potentially corrosive medium than water, research staff at the Whiteshell Nuclear Establishment in southeastern Manitoba have designed a form of individual concrete "mausoleum" to house canisters of cooled spent CANDU fuel. Each mausoleum is in the form of a vertical cylinder about 2.5 meters in diameter and about 5.3 meters high, standing on a concrete base in the open air. The concrete provides reasonably effective shielding. The dose rate ten meters from the surface of each canister is about background. The internal canisters are of high-quality steel, filled with inert helium gas and sealed. Experimental dry-storage mausoleums of this design have been in place for more than a decade at the Whiteshell center; regular monitoring and surveillance has to date revealed no problem, although one report has indicated the presence of minor surface cracks. In 1984 this Canadian dry storage technology was licensed to Pacific Nuclear Services, for offer to US utilities. The NRC has not thus far taken a position about its licensability in the US; that will presumably be the first question confronting potential American users.

As might be expected, the concept of storing spent fuel in dry conditions also got an early start where the fuel was designed from the outset to operate in dry conditions: in Britain. The story is, however, slightly curious. As described in the previous Cbapter, fuel clad in Magnox alloy is designed for use in the carbon dioxide environment inside the core of Magnox reactors - hence the name given to the reactors. The Magnox is not designed to survive for long in water. Nevertheless the first eight twin-reactor Magnox power plants of Britain's civil nuclear program were built with water-filled cooling ponds to take the spent Magnox fuel.

At the time - the late 1950s and early 1960s - the prevailing assumption was that the spent Magnox fuel would be sent within a year to Windscale, for reprocessing; the chemical onslaught of the pond-water would be brief enough not to matter. Be that as it might, when the ninth Magnox plant was ordered in 1963 the design incorporated not the usual water-filled cooling pond but instead a concrete storage magazine cooled by carbon dioxide. This plant, called the Wylfa power station, was built on the north coast of the island of Anglesey in north Wales. It was intended to be almost twice the size and output of any of its precursors. Spent fuel from the two gigantic Magnox reactors at Wylfa was taken out of the carbon dioxide atmosphere inside the reactors and discharged into one of the air-cooled vertical storage tubes inside the concrete magazine. The storage tubes themselves were sealed; they in turn were cooled by a flow of circulating carbon dioxide over their exteriors.

On the face of it this was obviously sensible. Even if the spent fuel was to be shipped ere long to Windscale for reprocessing, it made sense to keep the fuel in storage conditions for which it had been designed, to reduce or even eliminate corrosion. Indeed the Wylfa dry-storage magazine soon demonstrated its advantages. When British Nuclear Fuels Ltd ran into prolonged trouble with Magnox reprocessing at Windscale, from 1972 onwards, one consequence was its unilateral refusal to accept further shipments of spent Magnox fuel from Britain's commercial Magnox stations; for details see The Plutonium Business. As a result the Central Electricity Generating Board (CEGB) soon had cooling ponds filled with old, corroding Magnox fuel - at every Magnox station except Wylfa. At Wylfa the spent fuel resided happily in its CO_2 environment, free of corrosion. While the ponds at other stations grew more and more contaminated with radioactivity from leaking Magnox fuel, Wylfa stayed clean and wholesome.

Possibly because of this experience, the CEGB in the mid-1970s expanded the dry-storage facilities at Wylfa, adding two more magazines. These two additional magazines were cooled not by carbon dioxide but by natural circulation of ordinary air. They were commissioned in the late 1970s and have more than fulfilled the expectations of the CEGB and the designers, GEC Energy Systems. Spent Wylfa fuel is now discharged from the reactors into the CO_2 magazine. When it has cooled sufficiently, it is transferred into one of the air-cooled magazines. Careful monitoring of all three magazines has revealed no evidence of corrosion or serious deterioration of the spent fuel even after prolonged residence in the dry stores. GEC Energy Systems has since carried out lengthy investigations of the behavior of other types of fuel in the dry stores, with increasingly impressive results. Oxide fuel from Britain's advanced gas-cooled reactors and water-cooled fuel from American PWRs and BWRs all appear to remain corrosion-free and leak-tight essentially indefinitely.

The experience at Wylfa has been so comprehensively encouraging that GEC Energy Systems has for the past two years been running enthusiastic advertisements in the British nuclear press, extolling the virtues of its dry storage technology. More recently the government-owned National Nuclear Corporation (NNC) , Britain's nuclear power plant construction company, has begun to do likewise. Both GEC and the NNC stress, among other features, the modular nature of their dry storage vaults. The vaults can be built swiftly and in stages, adding further capacity as necessary without incurring premature front-end capital costs. This is of course a dramatic contrast to the financial terms offered by the reprocessors, who insist that customers put up capital payments as much as a decade in advance.

One nagging question remains. In the light of the unfortunate British experience with reprocessing and the gratifying British experience with dry storage, why has every nuclear power plant ordered in Britain since Wylfa in 1963 - seven twin-reactor plants, all gas-cooled - been built with a waterfilled cooling pond instead of a dry store? Even the two latest AGR stations still under construction, Heysham B and Torness, ordered in 1978, incorporate cooling ponds. In 1985, industry rumor has it that the CEGB is thinking about adding a dry store to Heysham B; if so, they have been thinking about it since at least 1981 with no sign of action yet. Whether the South of

Scotland Electricity Generating Board is having similar thoughts about Torness, and whether these thoughts will ever take concrete shape, is unclear.

What is clear is that the CEGB is now thinking hard about another form of dry storage of spent fuel. The first revelation of this change in attitude was given by the then secretary of the CECB board, appearing as a witness at the Sizewell B nuclear plant inquiry in February 1983. In his testimony he disclosed that the CEGB was considering the design of a single large-scale dry store, a central installation to take spent fuel from not one but many CEGB nuclear plants. The estimated cost of such a central dry store was put at some £100 million. The timing and substance of this proposal is still vague; but in 1985 it remains very much on the agenda. If in due course the CEGB puts forward a firm proposal for such a store, a site will have to be specified, as will arrangements for transport and handling of fuel from the participating power stations. The Nuclear Installations Inspectorate, which would be the licensing authority, has yet to express a view as to the licensability of such an installation in Britain. It would entail a very substantial concentration of long-lived radioactivity on a single site, with significant safety implications. However, the existing concentration of radioactivity at the Windscale/Sellafield site already raises just such questions - and the majority of the Windscale high-level inventory is stored in the more hazardous form of hot acid liquid, some 1200 cubic meters of it at present. It is hard to believe that the nuclear inspectors would not look with more favor on storage in the form of intact spent fuel. On the other hand it must be assumed, on the basis of recent developments in Britain and elsewhere, that there might be a less than eager reception from the local population that would have such a central store as a neighbor.

The concept of central storage of spent fuel has also been taken up elsewhere, in various guises. The German approach described earlier, utilizing separate casks as the primary storage medium, is perhaps the most basic; indeed it raises the question as to what advantage is gained by shipping spent fuel from all over Federal Germany to one of its most remote corners for storage. The claim is made that a single central store entails lower capital costs than several separate stores at power plant sites. Against this, however, must be set the costs of transport of spent fuel; and the Gorleben "central" store is not so much "central" in Federal Germany as peripheral. The impulse behind the German policy can almost certainly be traced to the institutional and political context, rather than to any considerations of technology or economics. The real reason for adoption of "central" storage of spent fuel at Gorleben is that any storage installation will be the subject of a lengthy licensing procedure, and the object of intense oppositions from some parts of the local community. The German electrical utilities take the view that it is preferable to concentrate all the licensing and other controversy at a single site, rather than having each operating power plant become the focus of renewed objections.

There is to be sure a further ramification to the Gorleben policy. The original "Entsorgung" plan of the Federal government foresaw final disposal of high-level radioactive waste in the salt dome under the Gorleben site. How this intention has evolved, and what it may imply in practice in the light of current proposals for spent fuel management, will be discussed in Chapter 5.

In the United States, official government policy until the late 1970s favored reprocessing and ultimate disposal of nuclear wastes in mined salt cavities. Utilities building plants before this time expressed their confidence in this policy by providing only a few years of storage capacity at power plants. But failures at reprocessing plants and with the proposal for a final salt disposal site created a quagmire. An ill-conceived proposed government salt repository in Lyons, Kansas ran into well-founded state opposition. Reprocessors at West Valley, New York and Morris, Illinois shut down. Utilities warned, loudly and repeatedly, that their spent fuel pools were filling up and that this would force their plants to shut down; then the Barnwell reprocessors ran out of money and into the opposition of Presidents Ford and Carter, both worried about plutonium proliferation. The public saw only growing piles of radioactive wastes accumulating in spent fuel pools, reprocessors going under - leaving the West Valley wastes to the state of New York - and a federal government apparently unable or unwilling to come up with any workable alternatives.

There was nothing sinister about the delay. Federal policy makers assumed that they would not need a final storage facility until reprocessing plants were operating and sending their wastes to the federal government. Glassified wastes from reprocessing were thought to be the form most suitable for storage in a repository; few policy makers or nuclear bureaucrats gave any thought to final disposal of spent fuel. Ergo, when reprocessing plants proved too unreliable and expensive to operate, federal nuclear bureaucrats saw their waste form change and timetables accelerate.

This combination of circumstances brought forth a solution that had been proposed earlier - temporary "away from reactor" storage of spent fuel in a centralized, water-cooled pond. This would buy time for reprocessing plants to regain political favor or for the Department of Energy to find and license a waste repository. These temporary facilities went by a series of awkward acronyms - RSSF, SURFF, AFR, and, most recently, MRS, for, respectively, "retrievable surface storage facility", "surface unreprocessed fuel facility", "away from reactor" storage facility, and "monitored, retrievable storage" facility. The deciduousness of the name has been a telling index of its political viability.

In the 1970s, nuclear bureaucrats never expressed much enthusiasm for centralized pools, concerned that they might be as difficult to license as a final repository, while taking attention away from reprocessing plants that they quietly hoped to license. Nuclear critics, meanwhile, opposed centralized pools as non-solutions that would only provide the industry with the appearance of a solution and the government with an excuse not to proceed with well-conceived final storage underground. Meanwhile, the on-site storage crisis - colorfully called "constipation" - became tractible.

But the Department of Energy announced in early 1985 that it would build a $1 billion "monitored, retrievable storage" facility (MRS) to handle spent nuclear fuel beginning in 1996 at the site of the abandoned Clinch River Breeder reactor in Tennessee. The Department justifies the MRS investment as an alternative to construction of new spent fuel pool pools at reactors after 1996.

It is an open question, however, whether the MRS is necessary. Based on analyses by Westinghouse, the dominant US reactor supplier, current high-density racks in at-reactor pools will run short of capacity by 2000; so-called maximum-density storage would buy another five years; but adding "high density poison racks" would extend this out to at least 2015. Rod consolidation would extend each of these dates by at least ten years; by combining this with high density poison racks, all the reactors in operation or under construction would have more than enough capacity for their projected lifetimes.

The choice of the abandoned Clinch River site may also prove politically troublesome if the presence of the plutonium in a centralized spent fuel pool rekindles reprocessing and the damped fires of breeder afficionados. At the moment, the US spent fuel controversy seems reasonably manageable. New racking techniques, consolidation, and dry storage can buy an unlimited number of years of breathing space without moving the fuel off-site. Underwater or in dry storage, both options reduce the transport of spent nuclear fuel, which could soon be a major undertaking. The existing backlog of spent nuclear fuel in the US is nearly 12,000 tonnes. By 1998, this will have swollen to 41,000 tonnes, with 3,000 tonnes added annually. It is expected that a repository would not be able to handle more than about 400-900 tonnes per year in the early years of operation. Even with two repositories working at top speed, it would take more than 30 years to place all this spent fuel underground. Transporting all of this waste is another problem. A study on nuclear fuel transport by the National Academy of Sciences showed that 2500-9000 shipments of nuclear waste frcm reactors would be required annually to empty spent fuel pools. This volume - nearly one per hour, twenty four hours per day, 365 days per year in the case of truck transport - would be logistically complex and politically troublesome. With a central storage facility located at the opposite end of the country from the likely site of a repository, the amount would only increase.

Railroad transport might ease the difficulty - as more spent fuel can be packed in a single shipment than in a truck cask - but the US rail system is outmoded, expensive, and slow. In addition, most railroad lines are opposed to spent fuel transport as ordinary freight. By adding to the number of shipments, the introduction of a central fuel storage facility could only complicate matters. Other fuel storage facilities would necessarily be built anyway at the site of proposed repositories, because waste could not be placed underground at rates even approximating the number of desired shipments. Alternatively, the central fuel storage facility could be enlarged to handle all fuel until repository space was available - a commitment to open-ended volumes and storage times at the MRS that would raise political objections.

The country whose spent fuel management policy has been most clearly thought out and laid out in public, both in theory and practice, is undoubtedly Sweden. Swedish spent fuel managers do, it is true, have an important advantage, although they do not see it that way: the total extent of the Swedish spent fuel problem is already known, and limited. The 1980 referendum result committed Sweden to build only the twelve power reactors now in operation, and to shut them down by 2010. According, the entire arisings of spent fuel for the whole Swedish nuclear program, from beginning to end, can be estimated to a high degree of accuracy - how much, what kind, when and where.

In the mid-1970s, when the nuclear power issue began to dominate Swedish politics, the Swedes instigated a series of exhaustive studies of the options for managing Swedish spent fuel, under the Swedish acronym KBS. In 1977 the Swedish Parliament passed an Act stipulating that no nuclear power station could operate until Parliament had been satisfied that there was a "safe" method of disposing of its spent fuel. In response to this so-called "Stipulation Act" the first KBS study, KBS-1, analyzed the option of having the spent fuel reprocessed, and then disposing of the high-level waste resulting. On the basis of KBS-1, and reprocessing contracts signed with British Nuclear Fuels and the French firm Cogema, the Swedish Parliament authorized the fuelling of several reactors. Meanwhile a second and third study, KBS-2 and KBS-3, were being carried out, analyzing the options for managing and disposing of spent fuel without reprocessing.

One condition of the BNFL and Cogema contracts was that in due course the Swedes would have to accept the return of vitrified high-level waste for final disposal in Sweden. This condition underlined the fact - commonly overlooked by policy-makers and politicians in nuclear industrial countries - that reprocessing does not make spent fuel disappear: on the contrary, it spreads the constituents into a variety of new materials, some hitherto absent and others just as difficult to dispose of as the original spent fuel. Accordingly, the Swedes realized that they would still face the problem of final disposal, reprocessing or no reprocessing.

The referendum decision of March 1980 defined the problem with a precision unavailable to countries with open-ended nuclear programs. By the time the last of the twelve Swedish nuclear plants was shut down in 2010, the total amount of radioactive waste produced would be 7500 tonnes of spent fuel, 100,000 cubic meters of low- and intermediate-level waste and 150,000 cubic meters of waste from decommissioning the power plants. By the early 1980s some 870 tonnes of spent fuel were already covered by the contracts with Cogema and BNFL; but Swedish policy thereafter decreed that no further reprocessing should take place. Instead preparations would be made to dispose of the remaining 6500 tonnes of spent fuel without reprocessing, after suitable conditioning.

The preparations went a great deal farther than paper research. The Swedish stations, like those elsewhere, had been built with water-cooled ponds of limited size and capacity. It was thus necessary to provide for adequate long-term storage of spent fuel, pending completion of investigations into final disposal. The KBS-3 concept, presented to the Swedish government at the beginning of 1983, foresaw a detailed procedure for dismantling spent fuel and encapsulating the fuel pins in a matrix of copper and lead. This conditioning procedure would entail construction of the necessary facilities at some single location; it was therefore appropriate to provide for long-term interim storage of spent fuel at a single central location, at which the subsequent conditioning could be carried out.

The Swedish nuclear utilities formed a joint company called the Swedish Nuclear Fuel and Waste Management Company, whose Swedish acronym is SKB, to organize and take responsibility for management and disposal of all their radioactive waste, including spent fuel. SKB in turn must meet the standards set by the Nuclear Power Inspectorate and the National Institute of Radiation Protection, the two licensing authorities. Waste management policy is laid down by legislation including the 1980 Act on Nuclear Activities and the Act on Financing. The Act on Financing requires utilities to pay a regular fee to the government, which goes into a fund managed by the National Board for Spent Fuel, the government oversight agency for the policy. The fee paid by the utilities must cover all "back end" costs of nuclear power production, including not only storage and disposal of all wastes but also decommissioning of all nuclear facilities.

As the Swedish policy has taken shape, so have the requisite physical facilities. A long-term storage installation for spent fuel has been constructed in a vast underground cavern near the Oskarshamn nuclear power plant south of Stockholm. The installation, with the Swedish acronym CLAB, will be completed in 1985. The CLAB installation incorporates a reception bay for unloading and handling spent fuel, and water-cooled ponds able to store 3000 tonnes of spent fuel. Future development of CLAB provides for its expansion to a capacity of 9000 tonnes of spent fuel - enough to account for the arisings from the entire Swedish nuclear program from beginning to end. The plan for CLAB is based on storing spent fuel for some 40 years, by which time the radioactivity will have fallen substantially, and it will be sufficiently cool to undergo further handling and conditioning.

A specially-designed nuclear transport vessel, called the Sigyn, came into service in 1982. It has already made controversial journeys to the French reprocessing plant at La Hague; but its main activity from 1985 onward will be to ferry spent fuel from Swedish nuclear plants to CLAB for long-term storage. No site has yet been selected for final disposal of vitrified waste and conditioned spent fuel; research is continuing, as will be described in Chapter 5. The other major installation now under construction is a disposal site for low- and intermediate- level waste, with the Swedish acronym SFR. The SFR installation is near the Forsmark nuclear power plant on the east coast of Sweden north of Stockholm; it will likewise be described in Chapter 5.

In 1985 the prospects for long-term storage of spent fuel, in any of several ways, look brighter than ever before. Research results indicate that water-cooled fuel can be stored in water-cooled ponds, or alternatively in gas-cooled magazines, with essentially no corrosion, for decades. Fuel that shows any sign of corrosion or other damage, whether on emerging from a reactor or after some time in a pond, can be enclosed in a sealed metal canister - "bottled" - and the bottle returned to the long-term store. Gascooled fuel can likewise be stored for decades in gas-cooled magazines, and in due course transferred to cheaper and simpler air-cooled magazines.

Certain major questions nevertheless remain. Chief among them is that of final disposal. Storage of spent fuel means just that: storage, not disposal. Although long-term storage now seem to be established as technically and economically feasible, the same cannot be said of final disposal, in whatever form or circurnstance. As will be discussed in Chapter 5, the distinction between storage and disposal is more than mere semantics; it carries with it technical, economic and ethical dimensions. The German nuclear industry expression "Endlagerung" - "final storage" - is a contradiction in terms, as will be discussed in Chapter 5.

With that proviso, however, storage of intact spent fuel, unlike immediate reprocessing, preserves all the subsequent management and disposal options. If research at length establishes the validity and necessity of some form of reprocessing as a precursor to final disposal, fuel that has been stored intact in the meantime can still be reprocessed; indeed, because of the decrease in its radioactivity and heat output, it will be both cheaper and easier to reprocess. The question of final disposal will be discussed in Chapter 5.

Storage of spent fuel does itself pose at least one more pressing question. In the wake of public disquiet and the apparent lack of adequate disposal arrangements for high-level waste in particular, reprocessors from the mid-1970s onwards have always stipulated that foreign customers must take back the vitrified waste from their reprocessed spent fuel. On the other hand, as mentioned in Chapter 3, same utilities have resorted to reprocessing primarily as a way to get spent fuel out of their power plant ponds, even if only temporarily. Might there not, therefore, be a case for the establishment of international arrangements for the storage of spent fuel? It is fair to surmise that most utilities no longer regard their spent fuel as anything but a liability, and would be prepared to pay a reasonable sum simply to have it taken off their hands into storage somewhere, pending satisfactory arrangements for its disposal.

The overriding reason for considering such a scheme is not, however, to bail out short-sighted utilities in nuclear industrial countries. The spent fuel from nuclear power plants may not be of much economic interest in the context of generating electricity; but it does contain plutonium, upwards of 10 kilograms of plutonium per tonne of fuel. Utilities in nuclear industrial countries dislike intensely any suggestion that their spent fuel might have military uses. On the other hand, utilities - particularly government-owned utilities - in some Third World countries may not have either the instinct or the opportunity to exercise such scruples. The wider implications of this issue will be discussed in Chapter 6. But it must be noted here that an international regime for long-term storage of spent fuel would cast a revealing light on the underlying motives of countries operating nuclear power plants. Countries that refused to participate, on the basis that they saw some national value to retaining their spent fuel on their own territory, would be legitimately open to suspicion as to their intentions. We shall return to this crucial concern in Chapter 6.

Chapter 5

Radioactive Waste

Every industrial process produces "waste": material that is of no further use. The waste may be anything fron completely innocuous to extremely hazardous in any of several ways. It may be a problem because of its sheer volume, or because it is in a form difficult to store or to dispose of. The various processes associated with nuclear power generation create a wide array of wastes, most of which share a distinctive characteristic: they are "radioactive".

The wastes of particular interest here are those created by the operation of a nuclear reactor. The chain reaction in a nuclear reactor releases a barrage of particles called neutrons; almost any material that is bombarded with neutrons becomes radioactive. However, much the largest inventory of radioactive material in a reactor is the accumulation of fragments of atom shattered during the chain reaction itself - so-called "fission products". Radioactive atoms - for example fission products like strontium 90 or cesium 137 - are unstable. Sooner or later they will break down spontaneously, and give off energetic particles called "beta rays" or packets of electromagnetic energy called "gamma rays". Radioactive atoms heavier than lead may also give off massive energetic particles caled "alpha particles". This alpha, beta and gamma radiation is dangerous to living tissue. It can kill cells, or damage them in such a way that they become cancerous. Reproductive cells may suffer genetic damage.

The biological effects of radioactive materials are not necessarily different in outcome from those of other hazardous materials like heavy metals or some organic chemicals. Nevertheless, even very small quantities of radioactivity may be potentially dangerous, and must be handled with care. It is not enough to exercise adequate care while radioactive materials are actually in use. Care becomes even more important once radioactive materials become waste. Hazardous waste material has all too often been simply "thrown away", without thought for what might then happen to it. Such haphazard disposal procedures are ill-advised whatever the material. For radioactive waste they are indefensible.

Radioactive wastes arise in different ways, at different stages of nuclear power production. The waste materials may be gaseous, liquid or solid. The concentration of radioactive atoms in waste varies over many orders of magnitude. The radioactivity may be so dilute as to be almost indetectible with sensitive instruments. At the other extreme it may be so concentrated that less than a minute in its presence will be fatal. Some wastes contain only radioactivity that rapidly dies away, said to have a short "half-life". Other wastes are much longer-lived, remaining significantly radioactive for tens or even hundreds of thousands of years.

The first stumbling-block that confronts policy-makers in coping with radioactive waste is the incoherent and inconsistent assortment of descriptions and categories into which the wastes can be divided. Broadly speaking, the criteria are of three kinds: according to the type of radioactivity, the concentration of the radioactivity, and the longevity of the radioactivity. On the basis of type, radioactive waste may be described as beta-gamma, as alpha, as "transuranic" (TRU) - implying alpha emission, or as "plutonium contaminated material" (PCM) - the rough British equivalent of TRU. On the basis of concentration, radioactive waste is described as low-level, intermediate-level, or high-level. On the basis of longevity it may be short-lived or long-lived.

Obviously these various criteria and descriptions overlap. Alpha emitters are frequently long-lived; high-level waste takes a long time to lose a significant fraction of its radioactivity both because of its initial concentration and because it includes an admixture of alpha-emitters; and so on. But there is a more serious problem. International organizations like the International Atomic Energy Agency and the OECD Nuclear Energy Agency have prescribed standards to serve as definitions for the different categories of waste: so much radioactivity per kilogram or tonne, and the like. In the US, for exanple, low level radioactive waste is not to contain more than 10 billionths of a curie of alpha emitting radiation per gram of waste. There is a similar volume-related standard on beta-gamma radiation, but it has become common practice to dilute radioactive waste that exceeds these limits with non-radioactive material. The result, of course, is that deadly material that should be carefully isolated frcm the biosphere somehow becomes safe because it is mixed with newspapers. Furthermore, these standards often have little to do with radioactive waste management in practice. Radioactive waste of whatever kind is a complex and far fram homogeneous admixture of materials. Any quantitative analysis can give at best an average sample of its radioactive constituents. In practice the various categories of waste are distinguished not by any analytic evaluation of their make-up but rather by their origins.

These origins are themselves varied. Radioactivity of course exists in nature, and is present both in the useful material - uranium - and the waste from manufacture of nuclear fuel. However, as noted above, the operation of a nuclear reactor creates new types and quantities of radioactivity. This report is concerned only with the "artificial" radioactivity thus created. A small percentage of this new radioactivity emerges frcm a nuclear power plant during its operation in the form of "running releases" of slightly radioactive gases and water. Water-cooled reactors create more running releases than gas-cooled reactors, boiling-water reactors more than pressurized-water reactors. The running releases from a power plant must meet standards set by the regulatory authorities; these standards are set in different ways in different countries. In the US, for instance, the standards lay down maximum permissible concentrations of radioactivity in water and air at the plant boundary. In Britain the standards are set by identifying so-called "critical groups" whose exposure to radiation from the plant must be kept below a stated maximum. Controversy persists about the adequacy of either form of standard; but it will not be described here.

Running releases are, as their name implies, discharged more or less directly into the environment. They are low-level (dilute) and short-lived, containing only beta-gamma emitters. They originate for instance in the drains from staff showers, the laundry for work-clothes and other plant areas that should be free of concentrated radioactivity and of alpha-emitting materials. Higher concentrations of radioactive contamination arise, for instance, in test laboratories at the plant, and in water-filled cooling ponds. Pond water accumulates radioactivity from the "crud" found on the cladding of spent fuel, and occasionally from leaking fuel pins. Pond water and other water with significant levels of contamination is passed through filters and over ion-exchange resins to remove most of the radioactivity. The water can then be discharged as low-level waste; but the filter sludges and spent resins may eventually contain too high a concentration of radioactivity to qualify as low-level. These semi-liquid materials then become "intermediate-level" wastes (ILW), and require more careful handling, storage and disposal, as will be described below.

The term "intermediate-level" is the vaguest in the lexicon of radioactive waste. It is applied in practice to all wastes that may be assumed from their origins to contain more a minimum concentration of long-lived alpha emitters, or more than a certain concentration of beta-gamma emitters, but do not actually give off measurable heat. Wastes whose radioactivity is so high that they give off heat are "high-level" or "heat-generating" wastes; in the US the acronym is usually HLW, whereas in Britain the acronym HGW has now been adopted. High-level or heat-generating wastes are those associated with the most concentrated accumulation of radioactivity in a reactor - the spent fuel.

An immediate question of policy arises: is spent fuel itself to be considered waste? If not, why not? and if so, how shall it be managed? As usual, the technical context of these questions is less influential than the institutional context. The radioactive wastes that arise during the operation of a nuclear power plant are clearly and unambiguously the responsibility of the plant's operator. The operator must monitor and control these wastes in compliance with regulatory standards, and bear the cost of doing so. For many years, however, nuclear plant operators in many countries were able to assume that much the largest fraction of the radioactive waste they created - the spent fuel - would be taken off their hands and become someone else's responsibility. Such continues to be in 1985 the attitude, for instance, of Britain's Central Electricity Generating Board. This passing of the radioactive buck has long bedevilled the search for satisfactory measures for nuclear waste management and disposal. After many years of havering, the institutional embroglio of radwaste policy in most nuclear industrial countries is more convoluted than ever. Before getting embroiled in it here, however, let us consider the technical determinants and possibilities for managing and disposing of the various categories of radioactive waste or 'radwaste' from nuclear power plants.

The ideal, of course, is to dispose of radwaste in such a way that it cannot subsequently return to the biosphere. Like certain other toxic wastes, radwaste is a type of material that biological systems have not evolved to handle. It cannot be neutralized or broken down; only isolation will keep it from interacting, probably harmfully, with living things, including people. Such absolute isolation is, however, impossible to achieve in practice.

Indeed, for many years in many places, radioactive waste of various kinds was simply dumped haphazardly, like other wastes whose toxicity was not at the time taken seriously enough. This casual approach even applied occasionally to the unambiguously dangerous high-level waste associated with spent reactor fuel: for instance, one of the problems now facing those dealing with the defunct Nuclear Fuel Services reprocessing plant at West Valley, New York, is an aggregation of 52 damaged spent fuel elements that were simply cast into concrete and buried on the site.

Setting aside for a moment those waste-disposal activities that have clearly fallen short of the necessary requirements for safety, there is a range of options available for managing and disposing of the different categories of waste. Consider first the least hazardous - short-lived low-level waste. As indicated above, gaseous wastes of this type are usually discharged direct to atmosphere. To meet discharge limits, gaseous wastes may first be passed through a filter that absorbs radioactive constituents and holds them for a time before releasing them again; such a delay may allow time for the radioactivity to decay to an acceptable level. Liquid low-level wastes are usually discharged direct into a waterway or coastal waters, possibly after filtration and ion-exchange to remove radioactive constituents. Solid low-level waste - used glassware, mops, brooms, mildly contaminated tools and the like - is usually gathered into containers for dumping.

In the US, until the mid-1970, there were six approved dumping sites available in various parts of the country for the bulky accumulations of low-level waste from nuclear power plants and other installations using nuclear materials. About 150,000 cubic meters are generated annually; enough, in the American lexicon, to pile a football field to the height of a hundred feet. Low-level waste was packaged and trucked - sometimes a thousand miles or more - to West Valley, New York, Maxey Flats, Kentucky, Sheffield, Illinois, Beatty, Nevada, Hanford, Washington, or Barnwell, South Carolina, to be dumped into open pits and buried. A series of disturbing experiences, however, led to closure of three of the sites, and severely restricted access to the other three. Maxey Flats accepted low-level waste contaminated with the especially toxic element plutonium, on the basis that the site was believed to be geologically and hydrologically able to confine the plutonium to the immediate location in which it was dumped. Belated research, however, established that plutonium from the waste was migrating through the soil of the site at an alarming rate. In response to local concern the state government imposed a tax of 10 cents per pound on waste; this heavy impost effectively closed the site to any further dumping. Similar problems led to the closure of the sites at Sheffield and West Valley.

The site at Beatty, Nevada, was temporarily closed in 1979, after it was discovered that staff at the site had been scavenging discarded tools and other material out of the waste and removing them for their own use off the site - even though the tools had arrived at Beatty contaminated with radioactivity. Washington State Governor Dixie Lee Ray - herself, ironically, a former Chairman of the US Atomic Energy Commission - declared that she no longer wanted Washington state to be the main receptacle for the entire nation's radioactive waste, and attempted to close the radwaste facilities at Hanford, Washington to waste from beyond state borders. The site remains open; in 1981 its private operators changed their name from Nuclear Engineering Company to the US Ecology Corporation, a startling alternative in the circumstances.

The Low Level Radioactive Waste Policy Act of 1980 was an attempt to restore order to the increasingly controversial issue of disposal of low-level waste in the US. Under the Act, groups of states were encouraged to form "compacts" to help to set up and finance radwaste disposal sites to serve the states belonging to the compact. After January 1986 states not belonging to a given compact could refuse to accept waste from states outside the compact provided the compact had been ratified by Congress. Pending creation of compacts and new dump sites, the existing facilities at Hanford, Washington, Barnwell, South Carolina, and Beatty, Nevada would remain open. The motives behind the Act were laudable; but the outcome may exacerbate the problem in the near future. Compacts were only formed in the regions with dump sites; but Congress has refused to ratify them because that would give compacts the authority to close off their sites to other states. Legislation has been introduced in Congress to extend the 1986 deadline by several years, in exchange for absolute limits on volume at existing sites, large fees, and a commitment to open new sites. At the time of this writing, however, Barnwell is the only such site actually open for dumping in the entire eastern side of the US; and states as far away as New York - home of West Valley - and Pennsylvania - home of Three Mile Island - are not at all happy at the prospect of having Barnwell closed to them in the near future. With or without new legislation, the stage is set for fierce, prolonged interstate confrontation.

If the disposal of radioactive waste can cause such difficulty in a country with the land-area of the US, it cannot be surprising that difficulties have also arisen in the more crowded confines of Europe. The situation in Britain in 1985 is especially fraught. The low-level liquid and gaseous wastes from British nuclear power plants have not usually been regarded as problematical. The discharges from the Windscale reprocessing plant are to be sure something else again, as will be discussed below; but all the power plants together discharge much less liquid and gaseous waste in total than Windscale. On the other hand the power plants do accumulate low- and intermediate-level solid waste. Some of the low-level waste is shipped to a site called Drigg, about five miles south of Windscale on the northwest coast of England. Until 1983 the reminder of this low-level solid waste was packaged in old oil drums, sealed with concrete or bitumen, loaded aboard a ship and dumped in the North Atlantic, at a point some 600 miles west of Ireland. The sea-dumping operation took place every summer from 1967 onwards, initially under the auspices of what is now the OECD Nuclear Energy Agency. For some years the participating countries included many OECD members. In the early 1970s, however, scientific and public concern began to raise doubts about dumping industrial waste in the ocean. An international gathering in 1972 drew up what came to be called the London Dumping Convention, laying down rules to control the dumping of materials at sea. The Convention did not itself ban the dumping of low-level radioactive waste; but in the following years fewer and fewer countries did so. Britain, however, persisted, until by the early 1980s Britain was dumping more waste than all the other remaining sea-dumpers - Belgiuim, the Netherlands and Switzerland - combined.

In response to harassment by the sea-going environmental organization Greenpeace, the British dumpers ordered a new vessel, with a central "moon pool" through which to drop the barrels of waste. No such technological option, however, allowed the British to sidestep the mounting opposition from other governments, especially those with Atlantic seacoasts. At the same time certain countries with Pacific coasts were worried lest the British example encourage other countries to dump nuclear waste - possibly also including high-level waste - in the Pacific. At the 1982 meeting of the London Dumping Convention the tiny newly-independent Pacific island countries Nauru and Kiribati put forward a resolution calling for a ban on sea-dumping of radwaste. After much debate the Convention passed an amended resolution calling for a moratorium on dumping, pending further research into its long-term safety. The British government noted that this resolution was not binding, and continued with preparations for the next annual sea-dump as usual.

By this time, nevertheless, the British National Union of Seamen had became involved in the issue. The union was unhappy at being engaged in an activity that ran counter to the wishes of a major international convention; and at length the NUS instructed its members not to crew the dumping ship. The rail unions, too, objected, and refused to crew trains to carry the waste-barrels to the port for transfer to shipboard. The British government, making the best of an embarrassing bad job, then agreed to suspend sea-dumping of British radwaste as the LDC resolution recommended. It also commissioned a report on sea-dumping from an atypically independent committee led by Professor Fred Holliday, an academic with no nuclear connections. The Holliday committee reported in the latter part of 1984; it declared itself broadly satisfied that sea-duniping posed no immediate hazards, but recommended its continued suspension pending further investigation. The London Convention will meet again in the autumn of 1985, at which time the British government is expected to press for the moratorium to be lifted. Whether it will be remains at the moment a very open question.

As the British government was getting itself into diplomatic hot water over radwaste disposal outside Britain, it was also getting entangled in a related controversy within its shores. The landmark 1976 report from the Royal Commission on Environmental Pollution, usually called the Flowers report after its chairman, had warned against a major commitment to nuclear power before satisfactory measures to deal with radioactive waste had been demonstrated. The Commission had reconmended the establishment of an independent nuclear waste management corporation, to cope with all the varieties of radwaste produced by British nuclear power. In response the government instead transferred policy on radwaste to the jurisdiction of the Department of the Environment, and appointed a Radioactive Waste Management Advisory Committee (RWMAC). In spite of the Corrmission's call for a fully independent body, the membership of RWMAC was drawn largely from the various branches of the British nuclear establishment - the Atomic Energy Authority, British Nuclear Fuels, the Central Electricity Generating Board, and the interested trade unions.

The nuclear organizations thereafter in 1983 set up their own Nuclear Industry Radioactive Waste Executive - NIREX. NIREX too had little in common with the independent body recommended by the Flowers Commission. Far from being independent, it was set up with a total staff of seven and a governing board of fifteen, all drawn from the waste-producing nuclear organizations. Furthermore it was charged with responsibility not for all wastes from nuclear power, but only with managing and disposing of low- and intermediate- level wastes. As will be discussed below, this gave NIREX no say in the main activity producing such wastes - reprocessing of spent fuel.

NIREX at once got off to a bad start. RWMAC, the official Advisory Committee, had recomnended that a number of potential waste-disposal sites be identified and studied for suitability, and that only after such a conparative study should any sites be proposed for actual development. Soon after its creation, nevertheless, NIREX announced that it was seeking permission to set up two disposal sites. One would be for intermediate-level waste, in a disused anhydrite mine under the main plant of Imperial Chemical Industries ICI at Billingham, on Teesside. The other would be for low-level waste, on land belonging to the CEGB at Elstow, near Bedford, north of London.

Local people around Billingham and Elstow were incensed, and at once formed action groups to oppose the NIREX plans. As the controversy grew fiercer, ICI, owners of the Billingham mine - and employers of many of the objectors - at length declared that they would not cooperate with NIREX. In early 1985 the Secretary of State for Environment at last issued a statement implicitly disowning NIREX's approach. He conceded that the Billingham site could no longer be considered, and requested that NIREX put forward not one but three sites for comparative study before any further decisions be taken. Even for low- and intermediate-level waste, therefore, British policy is thus at the moment in some confusion. For spent fuel and high-level waste it is at least equally so, as will be discussed below.

The French nuclear program is regularly cited as the ideal example of how to run a nuclear program. As earlier Chapters have already indicated, the French nuclear picture is not quite as rosy as industry propaganda paints it. French official policy on radioactive waste came in for serious criticism in the three reports from the independent government-appointed Conseil Superieur de la Surete Nucleaire, known as the Castaing committee after its chairman, Professor Raymond Castaing of the University of Paris. The traditional French approach of shallow surface burial has now been superseded by the construction of the Centre de la Manche near Cap la Hague, an elaborately engineered disposal facility for short-lived low-activity waste. French policy does not use the designations "low", "intermediate" and "high" for radioactive waste; instead it distinguishes between alpha-emitting wastes and the rest. Although the outward aspect remains calm and confident, French policy and procedures for radwaste management are now very much in flux.

In Federal Germany, the first major effort to cope with low-level waste was a program that got underway in 1968, in the disused Asse salt mine in Lower Saxony. Because it was billed by the Federal government as an "experimental" facility, it did not have to be licensed by the state government, nor was it. Film taken in the Asse facility during its early operation showed fork-lift trucks tipping yellow-painted barrels of waste off the edge of a salt precipice onto a jumbled pile of other barrels below. To some people the activity looked not so much like an experimental facility as like a disposal site pure and simple. At length, in 1978, as controversy was already mounting about the Gorleben proposals in the same "Land," the Lower Saxony government asked the operators of Asse how, when the "experiment" was over, they proposed to retrieve the barrels of waste. To no one's great surprise no satisfactory answer was forthcoming. At about the same time it was revealed that one of the interlevel floors in the Asse mine had collapsed, raising further doubts about what was going on there. The state government declared that pending resolution of these doubts, radwaste "experiments" at Asse had to cease.

The withdrawal of the Asse facility led of course to difficulties for those who had been supplying the "experimental" radwaste. The Federal government and the utilities' joint company DWK sought and found another site, a disused iron ore mine called Konrad, also in Lower Saxony. Official investigations satisfied the relevant bodies that the Konrad mine could meet the necessary criteria to become a low-level waste disposal site. Local objections at both Asse and Konrad, like those at

Gorleben, were overridden and discounted. One local authority commissioned the Gruppe Oekologie, a consultant body of independent scientists in Hannover, to prepare a study of the Konrad mine proposal. The Gruppe's critical report, released in 1983, was ignored by the licensing authorities. Konrad was given the go-ahead, and Asse was readied for disposal not only of low-level but also of intermediate-level waste. In 1985, however, both sites have yet to become operational.

In Sweden, however, the various official plans and projects for radioactive waste management and disposal have for some years been presented for consideration not only by independent scientists and engineers in Sweden itself but also to interested individuals and groups outside Sweden. These independent comments, analyses and criticisms have then been published officially - usually in English as well as Swedish - as addenda to the project description, to assist official policy-makers in Parliament and the regulatory agencies. The result has been a lessening of public suspicion of nuclear planning, often accompanied by tightening up of important details in the planning in response to the independent commentators and critics.

Swedish plans for low- and intermediate- level waste center on a facility with the Swedish acronym SFR. Like the CLAB spent-fuel repository, the SFR facility is underground; indeed it is also partly subsea, since it includes a substantial volume below the bed of the Baltic Sea off the coast near the Forsmark nuclear power plant north of Stockholm. In 1985 the SFR facility, begun in 1983, is still under construction; it is scheduled to be complete and ready for use by 1988. It is being cut out of crystalline rock; its rock caverns have been designed individually to accommodate the different categories of low- and intermediate-level waste. The first phase of construction will involve caverns able to accept about 50,000 cubic meters of waste. This will suffice until perhaps the year 2000; in the late 1990s a second phase will expand the site capacity to a total of about 110,000 cubic meters - enough to account for the remainder of the waste from Sweden's legally limited nuclear program, although the industry commentators are reluctant to put it in such terms. The wastes will be delivered from Sweden's other nuclear sites to the SFR facility by the nuclear waste transport ship Sigyn, mentioned in Chapter 4.

As will be apparent, there is a wide disparity between the geological and other physical characteristics considered acceptable for disposal sites for low- and intermediate-level wastes in different countries. Some countries like Britain and France accept shallow burial of minimally packaged low-level wastes. Sweden, on the other hand, has embarked on deep excavations in hard rock, for the same types of waste. The mobility of different radioisotopes in different types of soil and rock, under different hydrogeological conditions, is still a matter for major research programs in many places. Nor are packaging materials and techniques internationally agreed in practice. Both land disposal and sea-disposal leave important questions as yet unanswered.

"Disposal" is of course the crucial term. By definition "disposal", in intention and often in practice, is final and irrevocable. Disposal of a particular specimen of waste thus forecloses any other option for the management or alternative disposal of that specimen. The alternative to immediate disposal is some form of storage. As described in Chapter 4, spent fuel is now being stored in one of several ways in different countries, while work continues on establishing the least unsatisfactory form of final disposal of the radwaste it contains. If it is possible to store the high-level radioactivity of spent fuel, some would argue, surely it is likewise possible to store the less dangerous low- and intermediate-level wastes, at least until research has established that disposal practices are adequately safe even if irrevocable.

The nuclear industry tends to press two counter-arguments against this. One is that the volume of the less radioactive wastes is already troublesome and will become more so. The other is that it is irresponsible, not to say bad public relations, to go on storing wastes on the basis that there is as yet no fully satisfactory way to dispose of them. Neither of these counterarguments is entirely persuasive.

As to volume, setting aside uranium mine tailings, much the largest volume of low- and intermediate-level wastes associated with a given nuclear power plant will be that arising when the plant itself is decommissioned. Nuclear industry plans everywhere assume that defunct nuclear power plants will remain on their sites for decades before any definite removal. The plants themselves at that stage constitute radwaste; otherwise they could be dismantled forthwith. That being so, the total inventory of radwaste on the site would not be greatly increased if it included the low- and intermediate-level wastes accumulated during the operating life of the plant. Even the shielded storage facilities would constitute a comparatively modest contribution to the total volume of contaminated material awaiting final disposal in a suitable way at a suitable time.

As to the suggestion of irresponsibility in storing wastes, the irresponsibility arises not in storing them, but in creating them in the first place. Disposing of them prematurely, before determining that long-term safety criteria can be met, only compounds the irresponsibility.

The US is the only country thus far to have adopted a legally mandated timetable for final disposal of high-level waste and spent fuel. After decades of wrangling over the future of commercial reprocessing, the breeder, and plutonium recycling, there is at last a reasonable consensus among environmentalists and nuclear bureaucrats that unreprocessed spent fuel will be the form of high-level waste to be stored for eons. There is very little agreement on where, and under what standards, but, as described in Chapter 4, utilities have a wide choice of temporary spent fuel storage alternatives that could together provide 20-30 years more breathing space before a final repository need be operated.

It was, of course, not always this way. Throughout the 1970s, utilities and the nuclear industry complained bitterly about the lack of progress in government waste programs. Pools were filling up and reprocessing projects were shutting down. The Department of Energy finally began to see the vanity in its hopes for conmercial reprocessing. The agency turned first to a facility called the Waste Isolation Pilot Plant - WIPP - in New Mexico. But WIPP got bogged down in a morass of technical and political objections; originally, the plant had been proposed as a demonstration salt repository for transuranic contaminated defense wastes. In mid-stream, the project changed; it would be licensed by the NRC and handle, on a pilot basis, commercial spent fuel. Congress's Armed Services Committee took umbrage at any civil licensing procedure for defense-related wastes, and the project collapsed.

Meanwhile the Department of Energy sought other sites throughout the continental United States that might have suitable geologic strata and political climates. Much of it was done in a clumsy, high-handed, and discriminatory fashion: the state of Louisiana was promised a blanket immunity from any high level waste facility in exchange for its agreement to host a strategic oil stockpile, New Mexico was at first given state-level authority to veto any proposed repository, then promised a more ambiguous "consultation and concurrence" process, then promised nothing. No rock was turned without hostility; by 1981, thirteen states had barred the Department from investigating any strata anywhere within state borders.

In an effort to wiggle out of the quagmire, Congress enacted the National Waste Policy Act of 1982. The Act provided a procedure, schedule, and philosophy for licensing nuclear waste management facilities, including the "monitored retrievable surface" facility, if the Department of Energy considered it necessary. The NWPA, as it is called, called for the government to select three candidate repositories by 1985, open the first of these in 1992, and begin to accept commercial spent fuel deliveries by 1998. Its "philosophy" provided that one house of Congress - the Senate or House - could overturn a state-level veto of a proposed repository. It also provided for NRC licensing of sites and funding for potentially affected sites to challenge, on technical or economic grounds, a DoE selection.

In 1985, it is clear that the Department of Energy will miss its deadlines and some of the philosophical goals embedded in the Nuclear Waste Policy Act. Three sites - in Nevada, Washington, and Texas - have been ranked highest on the DoE's set of criteria for selecting a final repository, but state governments appear as disenchanted with the Department's behavior as ever. Even the Nuclear Regulatory Commission filed comments with the Energy Department indicating that the proposed Hanford site - in basalt rock, near the Columbia River - might not be able to contain radioactive waste for more than 1,000 years. The effort to find a suitable site could easily take decades.

All of which leads, inexorably, to the nuclear process that is far and away the major source of radioactive wastes of almost every kind: reprocessing. As described in Chapter 3, reprocessing begins with an intact fuel element - a piece of high-precision engineering, designed to operate in the challenging environment of a power reactor core and maintain its integrity while doing so. When this fuel element is discharged as spent fuel, it consists of perhaps 97 percent unused uranium, 1.5 percent plutonium and 1.5 percent highly radioactive fission products. The plutonium and fission products are dispersed essentially uniformly through the matrix of the uranium metal rod or ceramic uranium oxide pellets, and sealed inside metal cladding. As described in Chapter 4 they can be stored thus undisturbed, as a single unit. Furthermore the units can be numbered and counted, making it quite straightforward to keep track of them. Alternatively, the fuel element can be reprocessed. In the process the compact, high-integrity unit of a fuel element is turned into the following:

- uranium metal or powdered uranium oxide, whose subsequent potential usefulness is offset by the uranium-236 it now contains, an isotope that interferes with re-enrichment to make it more difficult and expensive than enriching fresh uranium;

- plutonium, initially in the form of plutonium nitrate solution depending on fuel burnup, anything from above 90 percent plutonium-239 to less than 70 percent, the rest being higher isotopes that lower the value of the plutonium as a potential fuel; the liquid solution must be converted to solid oxide for storage (or metal for bombs), another expensive industrial process;

- fission products, initially in the form of a highly-radioactive solution of hot acid;

- solid cladding scrap, also highly radioactive because of its contamination by fission products and plutonium;

- intermediate-level liquid waste from the uranium and plutonium finishing plants and from other stages of clean-up of process liquids and plant flushing;

- intermediate-level solid waste - filter-bed materials, ion-exchange resins and such;

- low-level liquid waste in enormous quantities from all the ancillary activities at the plant - showers, laundry and so on;

- low-level solid waste, likewise from ancillary activities;

- low-level gaseous waste - fission-product gases like krypton-85 and iodine-127, released into the plant's shielded cells when the fuel is broken open and dissolved, and thereafter discharged to the atmosphere.

Despite the strewing of the contents of spent fuel into liquid, gaseous, and solid forms of radioactive waste, an argument for reprocessing to reduce the waste problem is still made. In Europe and Japan, particularly, reprocessing is occasionally viewed as progress toward long term management of radioactive wastes, usually in the sense that doing anything with a problem sounds like a good idea. Up until 1976 or so, reprocessing was considered inevitable by nearly all participants in the debate. This ironically led to legislation in California, Germany, and Japan that conditioned the growth of nuclear power on progress in waste management. That was often interpreted to mean operation of a domestic reprocessing plant or a contract with a foreign reprocessor, but as we will see, the waste that comes out of a reprocessing plant and back to its place of origin may be significantly more dangerous than the spent fuel that went in.

By 1976, it was becoming clear that the breeder was not inevitable, that uranium was not especially scarce, and that reprocessing was proving technically difficult, costly, and politically troublesome. This set in motion a number of studies, mostly in the United States, on the differences between storage of wastes from reprocessing and spent fuel directly. The conclusions emerged clear. Reprocessing managed to separate a structurally sound, chemically unreactive fuel element into a wide spectrum of waste types none of which could be called structurally sound or inactive.

The most unavoidable environmental impact of fuel reprocessing begins as soon as spent fuel is dissolved in nitric acid. Gases are released -including iodine-129 and -131, xenon, tritium, and krypton-85. Some of these can be captured almost completely, but none perfectly, and standards in some nations are quite lax. The declining economic attractiveness of reprocessing only reduces the likelihood that radioactive gases will be controlled. Of all these products, iodine-129, with a half-life of 17 million years, is the least desirable gas to lose to the environment. When captured on filters or silver zeolite beds, these gases are usually treated as intermediate or high-level waste.

Reprocessing plants are designed to dissolve and remove in solution as high a percentage as possible of the uranium and plutonium in spent fuel. Every other consideration is at least secondary. In meeting its primary goal, most reprocessing plants have managed to extract 95-98 percent of the plutonium from the nitric acid solution. The remaining amount is unavoidably "lost" on contaminated equipment, clothing, paper, fuel hulls, or piping inside the plant. Ditto at plutonium fuel manufacturing plants, where many operations must be conducted with remote controls, owing to the much higher levels of radiation from plutonium than from uranium fuels. Little of this plutonium would end up in the "ideal" underground geologic storage facility; instead it would be disposed of as "low-level," "intermediate-level" or "transuranic contaminated low level" radioactive waste, terminology that is subject to as many differing interpretations as there as disposal techniques worldwide.

A recent assay at BNFL's Sellafield reprocessing plant, for example, determined that only 66 percent of the long-lived "transuranics" that went into the plant were present in the "high level waste" coming out. The remaining 34 percent were present in fuel cladding hulls, resins, sludges, and miscellaneous "plutonium-contaminated matter" - all treated as intermediatelevel waste in Britain, and therefore subject to much looser storage standards than either spent fuel or high level waste.

A further complicating factor is that reprocessing plants are not designed to remove radioactive isotopes that decay in time into plutonium or uranium. These materials include neptunium, americium and curium. All three are produced when reactor-grade plutonium is irradiated over long periods of time in a reactor. Instead of fissioning, the atom of plutonium "captures" a neutron. These weightier isotopes are rare in natural uranium fuels, but become quite a serious matter in fuels that have been reprocessed and recycled. Indeed, the heat from the curium-244 in ten-year-old reprocessed "high level" waste would be twice as great as all the plutonium and curium in "once-through" spent fuel. At length, it decays to plutonium 240.

Only one solvent has been found that can strip these transuranics from the high-level liquids in a reprocessing plant - it is known as DEPA for diethylenetriamine-penta-acetic acid - but this chemical has been used with only modest success on a laboratory scale. But the prospect of removing these long-lived radioisotopes - several of which decay into plutonium at length - is only that - a prospect. Two scientists with the UK Atomic Energy Research Establishment recently wrote on the awkwardness of separating and "burning up" these products: "first," they concluded, "the chemical separation of the actinides is so difficult that it seens quite unlikely it could be carried out routinely under industrial conditions. Secondly, the quantities . . . to be destroyed are such that a substantial proportion of a country's reactors would have to used for the purpose. . ."

One reason that "burning up" these actinides, including plutonium, is so difficult is that all of them are being created in reactor fuel almost as quickly as they are burned. This makes for an exhaustive process, with 15 or 20 recycles, and by the end of it a considerable amount of plutonium or things that decay into plutonium have ended up in low-level, intermediate-level, and high-level waste. Reprocessing, therefore, cannot effectively shorten the amount of time required to guard nuclear waste. Even so, an argument is put forward that reprocessing helps matters along by reducing the volume of radioactive waste to be disposed of.

Here again, whatever gains appear are often won at some expense. The 30 tonnes of spent fuel produced annually by reactors can be placed in steel and concrete containers for permanent subsurface disposal. These containers use about 15-30 cubic meters of space in a repository and must be spaced out to reduce the effects of radioactive heat on the underground geologic formation, a matter of considerable importance if a heat-sensitive medium, like rock salt, is selected. A year's waste, spaced out to reduce heat effects, uses up about 5800 cubic meters of repository space.

Reprocessed spent fuel creates numerous different radioactive waste forms, the most important of which is the glassified, or vitrified "high level" waste. The 30 cubic meters described earlier can be "reduced" to 3 cubic meters of high level waste, but there are another 15 cubic meters of cladding hulls (intermediate-level), 30-60 cubic meters of miscellaneous equipment waste (mostly TRU), and 15-30 cubic meters of low-level trash. Burning and other methods can consolidate these wastes, but, even so, the volume has climbed to about 50 cubic meters of waste, at least 80 percent of which is sufficiently contaminated to require - at least under US standards - deep geologic disposal.

One reason for the volume increase is, of course, the many chemicals that are added during reprocessing to dissolve and separate radioactive isotopes. Complex handling steps, often requiring remote-controlled equipment, also adds to waste volume. And the heat output from these combined wastes is also higher than for direct disposal of spent fuel; the plutonium is removed for use in fuel, but the americium, curium, and neptunium more than make up the difference for the space required in a repository is not 5800 cubic meters but 6300. Those handling and moving the waste underground would also appreciate the difference; the radiation rate (in neutrons per second per tonne) is forty times higher for reprocessed high level waste than for spent fuel.

The cost of radioactive waste management could, of course, override the environmental or safety considerations described above. Though the numbers are more suggestive than conclusive, recent studies by the US Department of Energy suggest a cost of about $125 per kilogram for disposing spent fuel or $127 for solidifying the liquids and disposing what is left of that kilogram after reprocessing. The $875 per kilogram cost of reprocessing must also be paid; thus no reasonable argument can be made that reprocessing makes waste management any cheaper.

Of course, the "science" of radioactive waste disposal is in its infancy. We may find it desirable to encapsulate spent fuel in materials that are less subject to corrosion or geologic movement than steel and concrete. Conceivably some forms of processing the fuel my prove desirable, but nothing we know today suggests that reprocessing is that technology. It can be seen as the technological step between the light water reactor and the breeder reactor, desirable; but not in the management of radioactive waste.

Chapter Six

"Civil" Plutonium and Nuclear Weapons

At the outset of the first nuclear programs, and for some years thereafter, there was no such material as "civil" plutonium. In 1985, in any but an arbitrary political sense, there still isn't. A key objective of all the early nuclear programs - in the US, Britain, the Soviet Union, and indeed in France and Canada - was the production of plutonium for military purposes. The first three countries fabricated the plutonium into bombs immediately. France held it in readiness until General de Gaulle decreed in 1958 that France must equip itself with nuclear weapons. Canada did not use its plutonium for Canadian nuclear weapons, but sold it to the US for the US to use in weapons, at a lucrative financial return to Canada.

While these activities were being pursued, nuclear engineers were to be sure convinced - except in Canada - that plutonium would also have to be used as fuel in power reactors, to overcome the then-perceived shortage of uranium. This plutonium would be, by definition, "civil" plutonium: but only by definition. There was, in the late 1940s, a brief flurry of interest in the idea of "denaturing" plutonium, so that it might be used as fuel but not as explosive. The idea probably arose by analogy with uranium. Natural uranium could not be used as an explosive, because the concentration of its "fissile" atom - uranium-235, able to support a chain reaction - was not high enough. Early nuclear analysts postulated that plutonium might be similarly "denatured," by assuring that it too contained too low a concentration of fissile atoms - in its case, plutonium-239.

The analogy was however misleading. The process of creation of plutonium by neutron-absorption in a chain-reaction ensured that, no matter how long the chain reaction ran, the fissile atoms of plutonium-239 would continue to constitute the majority. There would certainly be a build-up of plutonium-240, -241, and -242, to perhaps 30 percent or more of the total plutonium content. But the remaining plutonium-239, even at a concentration of less than 70 per cent, would still be an explosive. [The best index of plutonium's explosive capacity is the quantity of plutonium metal necessary for a "critical mass." For weapons-grade plutonium, this quantity is about 17 kgs; for reactor-grade, it is only four kilograms larger. An actual weapon uses a much smaller plutonium sphere - about 6 kilograms for weapons-grade - that is compressed by tampers driven by high explosives.] It would be somewhat less predictable in its behavior, and certainly more difficult to use, both when designing and when fabricating a bomb; but it would go off in an explosion that would leave no doubt about its nuclear antecedents.

Be that as it might, weapons-designers much preferred plutonium of high isotopic purity, upwards of 93 percent 239. There would less exposure to military personnel from the gamna rays and neutrons emitted by plutonium-240, -241, and -242. Over the years a terminology came into use, that described such plutonium as "weapons grade." The implied corollary was of course that less high-quality plutonium was not "weapons-grade," ergo, it could not be used for weapons. The correct interpretation was simply that weapons-designers did not want to use lower-quality plutonium. There was no profound physical reason for not using it.

Nevertheless, even in the 1980s nuclear people continue to employ this tendentious terminology, and even to expand it, usually with politicians and other non-specialists susceptible to the wilful confusion thus instigated. Official usage now alludes to plutonium as "weapons-grade," or "fuel-grade," or "reactor-grade," as though these categories were physically meaningful. In fact they are essentially a matter of convenience. The weapons-makers, as usual, get first pick: and they pick the plutonium that is at least 93 per cent 239. Then come the fuel-makers, who want to mix plutonium with uranium oxide to make "mixed oxide" fuel for power reactors - fuel enriched with plutonium-239 in place of uranium-235. They take the next cut, down to 80-85 per cent plutonium-239: so-called "fuel-grade" plutonium. What is left is "reactor-grade" - meaning that it is what emerges from a power reactor, not that it is considered suitable to put back into one.

The differing nominal value of these "grades" arises because of their origins, but is again subject to the nuclear version of voodoo economics, in which costs and values are assigned as if by magic. The shorter the residence-term of uranium in a reactor, the higher the purity of the plutonium-239 produced; on the other hand, a short residence-time does not produce much plutonium. Producing high-purity plutonium-239 thus entails frequent refueling and frequent reprocessing for a comparatively modest return in material; such plutonium is ipso facto expensive to produce. Its value, however, is determined according to military criteria: not how much it costs to use, but some convoluted calculus of how much it is worth just to have it and not use it.

A power reactor operating on a commercially acceptable regime runs its fuel to a burnup that produces plutonium containing a significant proportion of higher isotopes. The exact proportion increases with burnup, out to the maximum currently attainable in conventional thermal reactors. The plutonium recovered from high-burnup thermal-reactor fuel is "reactor-grade". Reactors that use metal fuel - the British Magnox reactors and their French cousins - cannot achieve such high burnup; their plutonium is accordingly of higher isotopic purity in 239. Furthermore these reactors are refuelled on load without being shut down. In consequence, for the first two or three years of operation, as the refuelling pattern is established, fuel is discharged at a low burnup. The plutonium it contains is at least so-called "fuel-grade," and may even be weapons-grade.

The value assigned to these various kinds of plutonium is often officially claimed to be so many dollars a gram, or so many tens of thousands of dollars a kilogram. What these nominal values mean in practice is obscure. They are presumably based on the eventual use of the plutonium as a fuel material, either in mixed oxide fuel for thermal power reactors or in fast breeder fuel. At the moment there is no commercial fast breeder power station in operation anywhere in the world. Those fast breeders now operating are prototypes with no pretensions to commercial competitiveness; the same epithet applies to the much-vaunted Superphenix, whose electricity will cost at least twice as much as that from conventional French stations. There is thus no factual basis upon which to found assertions about the true economic value of plutonium in fast breeder fuel. Similar considerations apply to the use of mixed-oxide fuel in thermal power reactors. Such usage has always to date been essentially experimental; the fuel has been used in order to evaluate its performance, not because its use makes any plausible commercial sense. By comparison with plutonium, as Chapter 2 indicated, uranium is cheap and plentiful, and will continue to be for many decades. Uranium enrichment is already far in excess of that required by postulated nuclear programs, and enrichers are battling for business. Plutonium cannot hope to compete.

Furthermore, the cost of recovering plutonium by reprocessing has hitherto been incorporated in the cost of dealing with thermal spent fuel, making the recovered plutonium virtually a "free good". If, as seems increasingly likely, reprocessing is to be carried out not for "waste management" but only for the express purpose of separating plutonium for use in new fuel, the cost of this new plutonium fuel must include the cost of the reprocessing that supplies the plutonium. As French economist Dominique Finon has shown, this reassignment of costs will make plutonium fuel of whatever kind prohibitively expensive, probably forever.

So much, then, for "civil" plutonium: as a credible economic and commercial concept it is a phantasm, and will almost certainly remain so. Why, then, in the face of overwhelming evidence to the contrary, do so many governments persist in pursuing nuclear power policies that involve massive expenditure - mostly of public money - on support for research and development for the use of plutonium fuel? The most persuasive answer is all too obvious. A nominally "civil" plutonium program is much the best way to guarantee a supply of plutonium for nuclear weapons.

Consider the historical context. The original nuclear-weapons states built "dedicated" military plutonium-production facilities - reactors and reprocessing plants - more than 30 years ago. Most of these first-generation facilities are already shut down; the remainder will be shut down within the coming decade. Those already shut down include, for instance, one of the Savannah River reactors, all the Hanford units except the N-reactor, and the G-1, G-2 and G-3 reactors at Marcoule in France. The eight Calder Hall and Chapelcross reactors in Britain are already well past pensionable age, and will be certainly shut down by the mid-1990s if not before. Yet these three states still put nuclear weapons at the center of their defense policy. It is inconceivable that the present American, British and French governments would allow themselves to reach a stage at which they no longer had the means available to produce weapons-plutonium; but none of the three governments have to date given the slightest indication of any intention to construct new dedicated weapons-plutonium production reactors. Where will they get their plutonium?

Unambiguous Civilitary Facilities

Despite perennial protestations to the contrary, governments in all three Western nuclear-weapons states have always been casual about distinguishing between "civil" and military plutonium. It need hardly be added that the same almst certainly holds true for the government of the Soviet Union; indeed, so far as is known, all Soviet plutonium, from all Soviet reactors, is the property of the State Committee on Atomic Energy, which is also responsible for weapons-production. China, for its part, has only in the 1980s begun to build nuclear facilities that are not explicitly military; all Chinese plutonium has always been military.

In the West, however, dating from President Dwight Eisenhower's "Atoms for Peace" speech before the United Nations in December 1953, there has been at least a rhetorical effort to distinguish between plutonium for bombs and "peaceful" plutonium. As indicated above, the distinction is founded not on fission physics but on administrative decisions; and even these administrative decisions have exhibited spasm of revealing ambiguity.

In the US, in the early 1950s, the Atomic Energy Commission sponsored four studies that concluded nuclear plants should be built with a dual purpose - electricity and military plutonium production - to be economic. The N-reactor at Hanford was designed and built as such a dual-purpose reactor, producing weapons-plutonium while generating electricity for sale to the Bonneville Power Administration.

The first "commercial" reprocessing plant, the Nuclear Fuel Services plant at West Valley, actually reprocessed more spent fuel from the Hanford production reactors than from all other sources (see Chapter 3); the separated plutonium was returned to the Atomic Energy Ccnmission. Since it came from the Hanford reactors it would have been so-called "weapons-grade"; it might well therefore have gone from the "civil" plant at West Valley into US bombs. The US Department of Energy, successor to the AEC, is of course responsible both for the Federal research and development program for civil nuclear power, but also for the US nuclear weapons program.

The situation in Britain is not even that ambiguous. The first eight power reactors in Britain, four at Calder Hall and four at Chapelcross, were built primarily to produce weapons plutonium; their electricity output was a by-product, sold to the public supply system. Unlike all the subsequent Magnox reactors these eight were built to be refueled off-load: to be shut down for the removal of all the fuel elements simultaneously - and presumably frequently. In the 1960s their operating regime was altered to improve their electricity output at the expense of plutonium-production; but no details of the change have ever been published. Even in 1985 the two stations are owned not by the electricity boards but by the government-owned company British Nuclear Fuels plc (BNFL) , and their operating statistics are not published, on the grounds that to do so might reveal how much plutonium they had produced. As will be described below, BNFL is not only a civil nuclear fuel company; it is also one of the key contributors to Britain's nuclear weapons program.

Yet another dimension to this official ambiguity in British nuclear affairs has surfaced gradually in the 1980s. It has emerged that in the late 1950s the government's defense chiefs were unsatisfied with the potential supply of weapons-plutonium. Although the Calder Hall and Chapelcross reactors were coming on stream, the two Windscale production reactors had been permanently shut down following the disastrous fire that wrote off the Number One "pile" in October 1957. Accordingly, it was decided that three of the newly-ordered "civil" Magnox stations be suitably modified to allow them to produce weapons-grade plutonium for the military. In the event, the three became just one, the Hinkley Point A station; and later official statements declared that the weapons-production capability had never in fact been implemented**.** This was in no way the result of belated scruples about the use of a "civil" plant for the production of weapons-material, but simply because Britain did not need so much weapons-plutonium after all. On the contrary: Britain was producing so much that it exported some, under circumstances that have in the past three years become hotly controversial.

The basis of the export was a Mutual Defense Agreement between Britain and the US, signed in 1958 and amended in 1959. It was a unique agreement between nuclear-weapons states, empowering the two governments to exchange nuclear technology and materials "exclusively for defence purposes" - in other words, to collaborate in the manufacture of nuclear weapons. The agreement has subsequently been renewed at regular five-yearly intervals, and in 1985 is still in effect. It casts an odd light on the stance of the US and Britain as co-sponsors of the Non-Proliferation Treaty, since it skates perilously near to contravention of the Treaty's first and most important Article. Be that as it may, both countries were and are weapons-states. In the early 1960s, under the Agreement, Britain shipped plutonium to the US in exchange for highly enriched uranium and tritium; the uranium was for use in fuelling Britain's nuclear submarines, the tritium for British hydrogen bombs. What has become particularly controversial in the recent past is the question as to where the exchanged plutonium originated, and what became of it in the US.

Persistent investigations, especially by Britain's Campaign for Nuclear Disarmament (CND), have elicited a succession of official statements that are internally hopelessly inconsistent. The main inconsistencies are these. In 1964 the then British government told Parliament that the US government had not used any British plutonium in American nuclear weapons, nor had it any intention of doing so. For some two decades all further Parliamentary questioners were referred to this brief statement as the final British government word on the matter. However, British plutonium had indeed been shipped to the US; and the Mutual Defence Agreement under which the shipments had taken place stipulated that such material was to be exchanged "exclusively for military purposes." Was the British plutonium used in American bombs or not? Either it was - and successive British governments were lying to Parliament; or it was not - and the shipments were in contravention of the Agreement under which they took place.

Furthermore, there was a curious disparity in official British accounting for its nominally "civil" plutonium stocks. No figures have ever been given for that plutonium deemed "military". But the government in 1977 provided the Windscale inquiry a breakdown of the "civil" stocks then held in Britain, and thereafter updated these figures in answer to Parliamentary questions in the early 1980s. According to government spokespeople, no record was kept distinguishing between plutonium stocks of different isotopic purity; plutonium was plutonium was plutonium. They added, however, that these stocks did not include any weapons-grade material. Thereby arose a clear-cut discrepancy, noted and pursued by CND and other investigators. As mentioned above, when a reactor is designed to be refueled on load, the fuel it discharges for many months after initial start-up is of low burnup, until the core has attained "equilibrium". The plutonium in this fuel will be more than 90 per cent 239 - weapons-grade by definition. Independent analysis suggested that the start-up periods of the "civil" Magnox stations might have produced about three-quarters of a tonne of weapons-grade plutonium. Yet the civil stocks itemized by the government were said to contain no weapons-grade material at all. What had become of it ?

One possibility canvassed was that this high-purity plutonium-239 had simply been blended with plutonium from fuel of higher burnup. Given the premium military value assigned to high-purity weapons-grade plutonium, this postulate seems scarcely credible. That leaves three further possibilities: either the weapons-grade material is still on hand in British "civil" plutonium stocks; or it has been used in British nuclear weapons; or it has been shipped to the US. If it is still in the "civil" stocks there seems no reason for the British government to deny the fact - granted that the appellation "civil" might be difficult to defend for a material specifically characterized as "weapons-grade". If, however, it has been used in British nuclear weapons, despite its "civil" origins, it does not do much credit to Britain's officially-proclaimed adherence to the principle of separation of civil from military nuclear activities, as laid out in the Preamble to the Non-Proliferation Treaty.

If, as now seems the most probable case, the weapons-grade material from British civil reactors was shipped to the US, what has become of it there? Again, the official pronouncements are internally inconsistent and contradictory. The issue was posed persistently by CND at the long-running public inquiry into the proposed Sizewell B nuclear station, which ended only in March 1985. The CEGB's chief witness insisted that no CEGB plutonium had been used in US nuclear weapons, or in any other nuclear weapons; he directed CND to the various government declarations to this effect. CND, however, produced a rearkable piece of evidence: a taped interview with Sir Christopher, later Lord, Hinton, first chairman of the CEGB. The interview had been recorded shortly before Hinton's death in 1983. In it Hinton, whose unswerving integrity was acknowledged even by most British nuclear opponents, did not pull his punches. Asked about the CEGB's assertion that none of its plutonium had ever been used in weapons, Hinton said that the one thing he was sure about was that in its evidence the CEGB "should not tell bloody lies". A more damning indictment it would be difficult to conceive.

In its closing statement to the inquiry the CEGB returned to the attack, deploring the fact that CND had not made the tape available earlier, at a time when it might have been possible to challenge Hinton. But the inconsistencies remained. In the US, in late 1984, Congressman Richard Ottinger exchanged letters on the subject with the then-Secretary of Energy, Donald Hodel. Hodel made it clear that the the US government considered itself free to use British plutonium as it saw fit, under the terms of the agreement by which the plutonium had been obtained - and regardless of whether it was labelled "civil".

The most recent US Administration pronouncements were therefore in line with policy proposals made earlier in the 1980s, in consequence of a perceived shortage of plutonium in the US. The plans to expand the US nuclear arsenal, advanced under President Jimmy Carter and adopted with enthusiasm by the Reagan Administration, were said to require more weapons-plutonium than could be supplied by the aging US production reactors. A plan to restart the L-reactor at Savannah River met with sharp legal challenge. In October 1982 it was revealed that the US was seeking to purchase five tonnes of plutonium from British civil stocks. When the idea came to light there was an immediate outcry in Britain. Sir Walter Marshall, combative doyen of the British nuclear establishment, insisted that the five tonnes of plutonium would be used for fuel for the Clinch River fast breeder, and would have nothing to do with US nuclear weapons. British critics pointed out that provision of British plutonium for Clinch River would free an equivalent amount of American plutonium for use in weapons; the British plutonium would thus assist, however indirectly, the buildup of US nuclear weapons. As the controversy mounted, it even brought an enraged response from the British union most stoutly supportive of Britain's civil nuclear program. The leader of the Electric Power Engineers' Association let it be known that if the deal went through the union would consider withdrawing its backing from the nuclear power program.

Meanwhile, in the US, the Reagan Administration was also upsetting its own domestic nuclear establishment. Ponds at US nuclear plants had long since begun to fill with spent fuel for which no long-term provisions had been implemented. Reagan officials proposed that the Federal government take this fuel off the utilities' hands, reprocess it either at Barnwell or - with modifications - at the military plant at Savannah River, and use the plutonium for weapons.

A report by the Department of Energy's Los Alamos laboratory had identified three options for producing new plutonium needed for new weapons: refurbish the old reactors at Savannah River and Hanford; build new ones; or use reprocessing plants to extract it from commercial waste. Los Alamos scientists defended the last option by arguing, "there is no technical demarcation between the military and civilian reactors and there never was one. What has persisted over the decades is just the misconception that such a linkage does not exist". In addition, the report added use of commercial plutonium for weapons would "[save] US commercial nuclear power generation frcm extinction by breaking the reprocessing impasse".

Be that as it might, the utilities, far from welcoming this solution to their spent fuel problem, were aghast. They had devoted two decades of effort to reassuring their customers that nuclear electricity had nothing to do with nuclear bombs: but here was the government proposing to undo all their efforts. US Nuclear Regulatory Commissioner Peter Bradford spelled it out pungently: "The average nuclear utility realizes that it does not need the controversy and that most of its customers do not want the feeling that when they turn on their lights they are also turning on the local atomic bomb factory".

At length, after many months of agitated uproar, the Reagan Administration abandoned this strategy, declaring that it had withdrawn its offer to buy British civil plutonium and that it had no intention of using US power plant fuel for weapons. However, the Department of Energy has continued its research and development program for a new oxide fuel head-end reprocessing plant to be built at Savannah River or Hanford. And another more troubling line of research also leaves very much open the use of power plant fuel for bombs.

For many years scientists and engineers in several countries had been exploring ways to use lasers to separate the isotopes of uranium. This work on laser enrichment had always been top secret; but public knowledge had always assumed that it was directed entirely toward enrichment of uranium.

In the early 1980s, however, it was revealed that laser isotope separation was also under investigation as a way of removing the undesirable higher isotopes from high-burnup power reactor plutonium. The only practical application of this technique would be the purification of power-reactor plutonium to weapons-grade. "Plutonium enrichment" has become a top research priority of the US Department of Energy, which wants a demonstration facility in operation by 1986 or 1987 and a budget of $560 million through the end of the decade.

The curtain of secrecy that has been drawn over laser purification of plutonium suggests that not only the US government but a number of others continue to regard the spent fuel stocks at their nuclear power stations as potential weapons-material, however "civil" its provenance.

The French Connection

Nor is spent power reactor fuel the only object of military interest in nominally "civil" nuclear programs. In 1982 two French analysts, Yves Lenoir and Michel Genestout, drew attention to a remarkable passage in an article in the official journal *Energies*. The article, by one L. Lammers, noted that the remaining French plutonium-production reactors, G-2 and G-3, were coming to the end of their working lives. Lammers, however, was unconcerned: "It is necessary to find a replacement, and this is assured (after Phenix) with Super-Phenix, which will be able to produce in the blanket around its core a sufficient quantity of plutonium of ad hoc quality to manufacture some sixty tactical atomic bombs a year".

In purely physical terms Lammers was undoubtedly correct. Within the core of a fast breeder the fuel consists of a mixture of ceramic uranium and plutonium oxides, between 20 and 25 percent plutonium. The plutonium need not be of high isotopic purity; "fuel-grade" will suffice, as indeed will "reactor-grade." The chain reaction in this so-called "driver fuel" releases a fusillade of neutrons - some of which emerge at the outer periphery of the core. They do not, however, escape. Around the core is a so-called "blanket," consisting of elements in which the material is not mixed oxides but ordinary uranium, or even the "depleted" uranium left over after enrichment. The neutrons emerging from the chain reaction in the core plough into this blanket uranium, and convert some of it to plutonium. There is not enough fissile material in this blanket to sustain a chain reaction there; and the "flux" of neutrons is thus much less intense in the blanket than it is in the core. The blanket material therefore undergoes a much lower "burnup" than the core (an easily reprocessed 6,000 megawatt-days per tonne compared with over 100,000 megawatt-days per tonne in the core).

Comparatively few uranium atoms are converted to plutonium; but of those which are almost all remain plutonium-239, rather than being converted successively into higher isotopes. Accordingly, even when a fast breeder is operating on a normal "civil" cycle, with the driver fuel staying in place for several years, the plutonium in the blanket is well over 90 percent 239: "weapons-grade". A fast breeder reactor thus carries out a form of indirect "plutonium enrichment": reactor-grade plutonium goes into the core, and weapons-grade emerges in the blanket.

This phenomenon happens willy-nilly: it does not have to be arranged. It will happen, furthermore, in any fast breeder power reactor of this design; however "civil" its provenance, the fast breeder produces weapons-grade plutonium. The physics, in nuclear terms, is straightforward. The politics, however, is anything but. The "plutonium-enrichment" effect of a fast breeder means that any fast breeder, whatever its ostensible civil role, is ipso facto a weapons-facility, capable of supplying the requisite material for the most sophisticated nuclear explosives. All that is required is the decision to use it.

Even for a fast breeder with a single national owner, like the French Phenix reactor, the implications are disquieting, as will be discussed below. Super-Phenix is a multinational project in which six different European countries share the ownership. The actual corporate structure is complex; essentially, however, France owns 51 per cent of Super-Phenix, Italy 33 per cent and a German consortium 16 per cent. The German consortiun in turn has smaller participation from Belgium, the Netherlands and Britain. If the throwaway comment in the Lammers article, and other similar comments by French military figures, are correct, only one conclusion can follow: taxpayers and electricity users in Italy, Federal Germany, Belgium, the Netherlands and Britain are helping to finance French nuclear weapons.

From any point of view this is an extraordinary state of affairs; indeed it is surprising, not to say lamentable, that it has not long since become an international scandal. It has, to be sure, led to bitter controversy in the Parliaments of the Netherlands and Federal Germany. Representatives in both countries demanded to know why their governments were permitting such a situation to continue. But official responses were anodyne and dismissive. The Dutch government replied, for instance, that the French had declared that no material used in Super-Phenix would be used for weapons. It was also asserted that France would be placing Super-Phenix under Euratom safeguards. Critics were unimpressed. They pointed out that the blanket plutonium was not "used" in Super-Phenix, a semantic loophole leaving France the option to use it in weapons, as its own officials had earlier claimed. The critics also noted that France, as a weapons-state, would have an escape clause in any safeguards agreement, permitting it if it so wished to withdraw facilities or materials from safeguards at will. Clause 14 of the tripartite safeguards agreement already in existence since 1978 between Euratom, the IAEA and Britain - another weapons-state - provided for just such an eventuality.

The Super-Phenix issue was further complicated by the arrangements for international participation in its fueling and operation. According to the terms of the relevant agreements, each of the participating countries would provide a share of the core material, including plutonium, proportional to the country's share of the project: 51 per cent from France, 33 per cent from Italy, and so on. American opponents of Super-Phenix declared in 1984 that almost all the plutonium so provided, even including some from France itself, was covered by agreements giving the US a veto over its use. The plutonium in question had been recovered from fuel originally enriched in the US. The enrichment had been carried out under agreements that included a so-called "pursuit" clause, by which the US was thereafter entitled to say what might become of the fuel or any material derived from it. If this analysis is correct - and it has been carefully documented, notably in a study by a Princeton scholar named David Albright - the US government is legally empowered to forbid the use of most of the plutonium earmarked for Super-Phenix. Any such attempt on the part of the US would of course create an international controversy recalling that of 1977 (for details see The Plutonium Business). Nor has the present US administration given any sign that it might be prepared to invoke its legal rights in the matter of Super-Phenix.

There is an another, even more mischievous, interpretation of the Super-Phenix situation. The Swiss physicist Michel de Perrot suggests, with considerable circumstantial evidence, that an independent European nuclear weapons force may be the ultimate goal of the European nuclear program. As we have noted earlier, both France and the UK have nuclear weapons and aging military reactors; both need separated weapons plutonium, if they are to meet their goal of adding more than 1000 new warheads (up from today's 162) to their arsenals by 1990. The cost of independent military plutonium production programs could only be measured in the billions of dollars; and the use of civilian facilities for weapons production would be prohibited by Treaty and public opposition in every European nation but France. In addition, the idea of an independent European nuclear weapons force, involving West Germany, has attracted much political support in the last five years, generally out of the fear that a US "umbrella," particularly under a Star Wars defense system, would not protect Western Europe. Leading politicians in France, including Mitterand, Chirac, and Giscard d'Estaing, have all voiced their opinion that Federal Germany - despite its agreement not to develop weapons on its own soil - must be involved, at least to the extent of having a "dual key" on any European nuclear weapons placed in Germany. Thus Super-Phenix and the European breeder consortium may underlie the development of weapons plutonium for an independent European nuclear force quietly paid for by electricity users and never debated publicly in any of the assisting nations. The negotiators of the Non-Proliferation Treaty saw no possibility that a non-nuclear weapons nation could help a weapons nation acquire more; perhaps it is time for the Treaty to imclude such an injunction.

The complacency of the US and European governments about being associated with France on the Super-Phenix project, despite its explicit military connotations, would be ample reason for concern. The overlap of civil and military nuclear activities is blatant enough without such an egregious manifestation. On 10 January 1984, however, the goverrnments of France, Britain, Federal Germany, Belgium and Italy signed an agreement undertaking to pool their fast breeder research and development into a joint multinational program. The intergovernment agreement was followed within weeks by similar agreements between the national nuclear agencies of the participating countries, by their reactor-manufacturers, their electricity supply organizations and their nuclear fuel companies. On 25 May 1985, the UK Atomic Energy Authority and British Nuclear Fuels announced that the UK would contribute to this international effort by completing in the mid-1990s a $250-375 million breeder fuel reprocessing plant at Dounreay.

These agreements, including the initial one between the governments, received no prior discussion in public or in Parliament. Yet even the most casual analysis indicates that they commit the participating governments to an almost open-ended outlay of public funds, for an activity which is long since admitted to have no prospect of commercial payoff until at least 2025 - if then. Any onlooker must wonder what lies behind this stubborn official insistence on ploughing ever more effort and money into the plutonium-fueled fast breeder; and more and more onlookers appear to be reaching the same conclusion. If there is no conceivable "civil" justification for the activity, its objectives can only be military.

Consideration of the British position certainly reinforces this suspicion. As mentioned earlier, Britain's dedicated weapons-plutonium reactors at Calder Hall and Chapelcross are all now at least 25 years old. British Nuclear Fuels, which operates them for the Ministry of Defence, has recently asserted that it foresees no reason to shut them down in the near future. Be that as it may, other official nuclear policy statements indicate that the reactors will certainly be shut down before the turn of the century. Yet Britain is embarking on a major expansion of its nuclear arsenal. It is hard to believe that the British government does not already have plans to replace Calder Hall and Chapelcross with other sources of weapons-plutonium.

The government remains committed to the purchase of the Trident system from the US, which will be fitted with British warheads. The plutonium for these warheads may well, of course, be recycled from that now in Polaris warheads or other aging British nuclear weapons. Such recycling is one of the less-publicized activities of British Nuclear Fuels at Windscale/Sellafield. Even the highest-quality weapons-plutonium contains a small admixture of plutonium-241. This isotope is fissile; but it has a half life of only 13 years, and decays into americium-241, which is much poorer weapons-material. The plutonium in a nuclear warhead that has remained for some years unused contains a build-up of americium that may make its potential explosive performance unsatisfactory to its designers. Accordingly, old nuclear warheads are "laundered" to remove the americium. In Britain this laundering is carried out in the Windscale reprocessing plant at Sellafield.

This is to be sure only one of the military activities of British Nuclear Fuels. Its annual reports omit any mention whatever of its military role. Nevertheless, despite this coyness, and despite its name, BNFL is by no means only a civil "fuel" company. BNFL produces all the plutonium for British nuclear weapons, at Calder Hall and Chapelcross, and recovers and purifies this plutonium at Sellafield. It also produces tritium for hydrogen bombs in an installation constructed at Chapelcross in the mid-1970s.

At least one commentator close to the British nuclear establishment has written that - despite the Windscale inquiry - there never could have been any doubt that the Windscale Thermal Oxide Reprocessing Plant (THORP) would be built, since it would be needed for Britain's nuclear weapons program after the shutdown of the B205 chemical separation plant. B205 has been in service since 1964. At the Sizewell inquiry in October 1984 a BNFL witness conceded under cross-examination that Euratom had been attempting for a decade without success to have its safeguards inspectors admitted to the reprocessing facilities at Windscale. They had been denied admittance because - as the BNFL witness confirmed - the plant was used to reprocess not only civil Magnox fuel but also weapons-material. Indeed he went on to say that both categories of material were sometimes passing through the plant at the same time. In other words any putative distinction in Britain between "civil" plutonium and any other kind is not based even on physical discrimination between batches of material. The arbitrary nature of the "civil" and other labels could hardly be more clearly demonstrated.

Even this stubborn affront to the central postulate of the international safeguards regime - the presumed separability of civil nuclear activities from military - stirred only brief and limited controversy in Britain. The British government continues to declare its lofty commitment to non-proliferation and the Non-Proliferation Treaty, even as its own plutonium-processing plants serve both civil and military clients simultaneously, dividing up the plutonium simply by official fiat: this lot is for weapons, that lot for fuel. It is to say the least a sorry reflection on the regard in which Britain holds its responsibilities as one of the three sponsors of the NPT.

It is also a devastating example to set those many countries that do not yet explicitly possess nuclear weapons but feel they should guarantee themselves the option. They need only look to Britain, where it is evident that a plutonium program meeting all the criteria for designation as "civil" nevertheless supports more than adequately a major nuclear weapons program.

Soviet Nuclear Power and Weapons

The Soviet Union, like its Western weapons-state counterparts, has had from the first a nuclear program in which civil and military objectives overlap. It is still, to be sure, difficult to come by accurate current information about the Soviet nuclear program. Its military aspects are of course kept as secret as international intelligence will allow; and even when Western intelligence makes assertions about Soviet nuclear-weapons activities such assertions must be regarded with a measure of skepticism. At the same time, the Soviet civil nuclear progran suffers from another kind of secrecy: that imposed by Soviet officialdom over any less than successful Soviet undertaking. Official Soviet pronouncenents about the country's nuclear power are prone to a sanguinity that makes the Atomic Industrial Forum look cautious. The actuality, as Chapter 2 above indicated, is a good deal less impressive.

Be that as it may, however, the long-standing official Soviet nuclear policy, so far as it can be discerned, mirrors faithfully that still pursued in Europe, centered on reprocessing, fast breeders, and plutonium fuel. Like its Western equivalent, this Soviet policy has experienced a series of reverses that might in other circumstances have been terminal. Its prototype fast breeder, the BN-350 at Shevchenko on the Caspian Sea, had the usual protracted trouble with steam generators; in 1985 it is reportedly operating at less than half its design output. According to Soviet expectations cited in the Western press in the mid-1970s the next unit in the program, the 600-megawatt BN-600 at Beloyarsk, was at least three years behind schedule in starting up. It is the largest fast breeder thus far to come into operation; but its technical status in 1985, and whether it has in fact attained its design output, is unknown. Soviet nuclear officials have told their western colleagues that the main problem with the plant is economic, with capital and operating costs "worse" than for conventional reactors. In the mid-1970s Soviet nuclear plans anticipated moving directly to the construction of a BN-1600, more than double the size of the Beloyarsk plant, indeed the largest single power reactor of any kind ever built. By the early 1980s this plan had been quietly set aside; the next fast breeder would be a BN-800, only half the size, and only a modest step larger than its precursor. In 1985 this unit is still unlisted in the most recent catalogues of the world's reactors. It has yet to even get the go-ahead for construction, with economics "much more difficult in the design and construction of BN-800 than BN-600" the principal stumbling block.

It goes without saying that the economic status of the Soviet fast breeder is, to redeploy slightly the vivid phrase of Churchill, "a mystery wrapped in an enigma". The stated cost of Soviet nuclear electricity is conjured up even more obscurely than that of nuclear electricity in the West; and the cost of fast breeder electricity yet more so, especially as regards the financial status of the plutonium involved. The fresh fuel for the Soviet plants uses plutonium that is, presumably, separated in the top-secret nuclear installation near Chelyabinsk in the south Ural mountains; no other reprocessing facility is known to exist in the Soviet Union. The Chelyabinsk facility is of course primarily a nuclear-weapons production plant; in this respect it is a first cousin to the Windscale reprocessing plant in Britain, whose weapons-role may not be "primary" but is undoubtedly a key to its continuing existence. Like the Windscale plant, the Chelyabinsk plant must therefore also have a dual role.

It is unclear as to whether the Soviet Union is actually reprocessing the spent fuel from its "civil" VVER (PWR) and RBMK (water-cooled, graphite-moderated) power stations, or indeed what is done with this spent fuel otherwise. Shipping the quantities involved all the way from the western Soviet Union to the south Urals would be punishingly expensive. Unlike for instance Japanese nuclear power plant operators, Soviet nuclear power plant operators do not have to comply with regulatory requirements that force them to ship spent fuel half way around the world just to get it out of their cooling ponds.

On the other hand, the dedicated Soviet plutonium production reactors for weapons, reported to be sited at Troitsk in central Asia, have been in service since the 1950s. Their status in 1985 is unknown. As is the case in Western weapons-states, nothing has been revealed officially about any plans to replace the old units when they are taken out of service. It may well be that the Soviet Union, like the current US administration, sees no problem in acquiring its weapons-plutonium from spent power-plant fuel. Plutonium from the VVER plants will suffer from the same drawbacks as that from Western PWRs; the plants must be shut down for refuelling, and any economic fuelling-scheme will thus produce high-burnup plutonium of low isotopic quality - less than ideal for sophisticated bombs. The distinctive Soviet RBMK design, however, has individual fuel channels like British gas-cooled reactors and Canadian CANDU reactors. Like these Western types the RBMK may therefore, so far as is known, be refuelled on load. If so, one or more RBMKs could be operated to discharge fuel of burn-up sufficiently low to produce high-quality "weapons-grade" plutonium. Alternatively, or in addition, the blanket-plutonium from the BN-350 and BN-600 could be used for weapons. If so, the policy would be in line with that already apparently espoused in France and tacitly accepted by other Western nuclear countries, whether or not they themselves possess nuclear weapons.

One related feature of Soviet nuclear policy is nevertheless curiously interesting. The Soviet Union has supplied VVERs to most of its Comecon partners, including Bulgaria, Czechoslovakia, Poland, East Germany and Hungary, and also to Finland and Cuba. (It refuses to export breeders, graphite reactors, or any fuel cycle facilities.) The fuel-supply contracts for the VVERs stipulate that spent fuel from the plants must be returned to the Soviet Union, nominally for reprocessing. Whether in fact such spent fuel has been and is being shipped to the Soviet Union, or whether it is then being reprocessed there, is unknown. But the contractual stipulation makes clear that the Soviet Union has no desire to allow its client countries to do as they wish with their spent fuel, and with the plutonium it contains. It is yet another manifestation of the attitude that typifies the "non-proliferation" policy of the weapons-states, as they continue to pursue civil and military nuclear aims with the same facilities and organizations: "do as I say, not as I do."

Japan and Federal Germany

The example of ambiguity set by the plutonium program of the nuclear weapons states is mirrored in certain aspects of plutonium programs in non-weapons industrial states - albeit, for obvious reasons, more discreetly. The two countries of particular interest in this context are Federal Germany and Japan. Both countries have long-standing commitments to reprocessing, fast breeders and the use of plutonium fuel. Furthermore both countries are prominent proponents of MOX fuel for thermal reactors, an option that has elsewhere been largely discounted on the grounds of its unimpressive economics.

The political circumstances of Federal Germany and Japan are of course peculiarly distinctive. After the end of World War II both countries accepted agreements imposing formal limits on their nuclear activities. The effect of these agreements has been to circumscribe the military nuclear aspirations of both countries. Nevertheless in both Federal Germany and Japan certain political factions have long sought ways of ensuring that their countries could acquire nuclear weapons. In Japan, for example, stubborn opposition from such a faction in the Diet delayed the country's ratification of the Non-Proliferation Treaty until mid-1976. In Federal Germany a number of troubling questions have arisen about the country's international nuclear collaborations, especially that with Argentina. The Bonn goverment has vehemently denied any underhanded dealings, but reputable journalists have reported a series of curious episodes that suggest otherwise.

In light of these unresolved doubts about German and Japanese nuclear intentions it is all the more striking that these two countries should be the most vigorous proponents of "civil" plutonium technology among the industrial countries not at present possessing nuclear weapons. It is, of course, impossible to draw any clear-cut conclusions; the evidence of ambiguity is at most circumstantial, and is heatedly challenged by government and nuclear officials in both countries. While acknowledging the official denials of any weapons aspirations on the part of either Federal Germany or Japan, it is nevertheless necessary to point out the undeniable corollary. Such aspirations may well be entirely lacking at the moment; but the existence of the "civil" plutonium programs in each country will make any future change of mind in favor of weapons-acquisition technically feasible, straightforward and amenable to immediate implementation.

Nuclear Weapons and Power in the Third World

The plutonium programs in the nuclear industrial countries have at least a historical plausibility. They got underway at a time when the ruling assumptions foresaw a crucial role for plutonium as civil fuel, in the context of the nuclear power programs then anticipated. In other countries, however - in particular India, Pakistan, Argentina and Brazil - the plausibility of "civil" use of plutonium demands from onlookers a total suspension of disbelief. With the exception of the two small Tarapur BWRs, India's power reactors are of the CANDU heavy water design that uses natural uranium, unenriched. Pakistan's sole power reactor likewise uses natural uranium, as do two of the three power reactors in Argentina. The spent fuel from this type of reactor emerges with the fissile content of its remaining uranium well below that of fresh natural uranium, down to less than 0.5 per cent. Such uranium cannot economically repay recovery for reuse. There is to be sure plutonium in the spent fuel; but the scale of the power program in these three countries falls far short of that required to support fast breeders. Convoluted arguments have been advanced to the effect that the plutonium could be used to reenrich the depleted recovered uranium to the equivalent of natural uranium. The cost and pointlessness of such an exercise strains credulity to breaking point.

A decade ago the Brazilian program was impressively ambitious. It has proved, however, impressively futile. Only a single power reactor has been completed, far behind schedule. Of the eight reactors ordered from Kraftwerk Union in 1975 only one is still actively under construction; a second has been virtually abandoned, and the later units pushed into the distant future. But Brazil is still at work on fuel cycle facilities including a pilot reprocessing plant at Resende, whose foreseeable relevance to the Brazilian power program in 1985 is tenuous to the point of absurdity.

The same situation applies in Argentina. The civilian government under tight fiscal policies has stopped federal funding for a 698 megawatt heavy water reactor and a pilot reprocessing plant at Atucha, a uranium fuel fabrication plant at Cordoba, and a pilot heavy water production plant at Zarate. The technology for these plants came mainly from Canada and Germany, but growing militancy coupled with unwillingness to accept safeguards or sign the Non-Proliferation Treaty led to the termination of some aid. The cutoff came too late to stop Argentina from completing the most worrisome facilities independently; however economic factors may well stem the growth in Argentina's nuclear capabilities and the power of its nuclear bureaucracy. The situation is, however, volatile: with its complete or nearly-complete facilities, Argentina could build bombs; its civilian government will not sign the Non-Proliferation Treaty, and even if it did, right-wing parties in Parliament would prevent ratification; with a heavy debt and no nuclear export standards, the temptation is great to sell nuclear equipment to questionable customers. In spite of this, news reports indicate a growing consensus in the Argentine government that the country does not need and cannot afford any expansion in its nuclear power effort. With ample hydroelectric power, electricity surpluses are projected to last twenty years. One Argentine nuclear expert conmented recently, "with 1000 percent inflation, there is no future for the nuclear industry here".

No complacency whatsoever is appropriate for India or Pakistan. Though it had promised to use its nuclear aid "only for peaceful purposes," India tested a nuclear explosive in 1974 using plutonium reprocessed from the spent fuel of an unsafeguarded Canadian research reactor supplied with heavy water from the United States. In the aftermath of the test, much aid was cut off, but India already had access to both reactors and reprocessing - the latter gained in the 1960s from US and French private firms. Between its 1974 test and 1984, India, for whatever reason, has not tested new weapons or added, so far as is known, to its stockpile. Indira Gandhi, and her successor, Rajiv, have consistently denied having nuclear "weapons". However in 1985, Prime Minister Rajiv Gandhi, responding to increased political pressure inside India, said that India would have no choice but to build weapons if Pakistan succeeds in obtaining the bomb. The Indian nuclear bureaucracy is well prepared; as of this writing, India has the Dhruva 100 megawatt research reactor, the 40 megawatt Kalpakkam pilot fast reactor, the 235 megawatt MAPP-1 power reactor, and the recommissioned Trombay reprocessing plant operating without international safeguards. Indeed, India held up MAPP-1 for more than one year so that they could use their own heavy water rather than safeguarded material from the US, Canada, or USSR. By the early 1990s India could be producing enough plutonium for sixty nuclear bombs annually; an expensive decade-long space and missile program has probably given India the ability to fire warheads deep into China or Pakistan.

This threat could rapidly materialize with any nuclear test in Pakistan. Two successive Pakistani governments have secretly pursued nuclear weapons. As early as 1965, then Prime Minister Zulfikar Ali Bhutto declared "if India builds the bomb, we will eat grass or leaves, even go hungry, but we will get one of our own". His successor, President Zia, agreed with Bhutto on little else but nuclear weapons. Since 1975, with financial aid from Libya and Saudi Arabia, Pakistan has stolen plans and secret nuclear equipment from under the noses of US, Canadian, and European firms. A western aid crackdown was shortlived, lasting only until the Soviets invaded Afghanistan. By 1984, the director of the Kahuta nuclear center boasted that no technical obstacles remained in the way of obtaining weapons-grade nuclear material. US military aid has provided F-16 fighter airplanes as potential launch vehicles.

The plutonium programs in these four countries have essentially nothing to do with their supplies of nuclear electricity, now or for many years to come. Why, then, are they still so assiduously sustained? There is of course the unfortunate but undeniable international "prestige" associated with competence in plutonium technology. But this "prestige" itself arises because of its unstated corollary: a country with demonstrable competence in plutonium technology, however nominally "civil", is only one short step from nuclear weapons.

The four countries here discussed have always declined to become parties to the Non-Proliferation Treaty, or to accept full-scope safeguards. All four countries have fuel-cycle facilities to which no safeguards are applied. They base their refusal to accept safeguards on the assertion that the facilities in question are indigenous technology, unrelated to any from foreign suppliers. But the very refusal automatically gives rise to obvious suspicion about the motives of the countries constructing and operating such facilities, especially in light of their apparent irrelevance to the nuclear power programs in the four countries.

'Safeguarding" Plutonium

In an ironic sense the refusal of some countries to accept international safeguards on certain facilities might almost be construed as a vote of confidence in the safeguards regime. The paradox has always been the insistence by interested parties that acceptance of safeguards entails no significant constraint on a country's nuclear activities provided they be "peaceful". Some nuclear activities - those, for instance, involving separated plutonium - are "peaceful" only insofar as they are not actively devoted to making bombs; no technical barrier prevents the decision to redirect such "peaceful" activities immediately and effectively into weapons-manufacture. Yet several countries - Argentina, Brazil, India, Pakistan, Israel and South Africa, all nominally non-weapons countries - refuse to accept safeguards on relevant installations. The refusals, however, have more to do with national pride and sovereignty than with any inference that acceptance of safeguards might seriously impede potential weapons-development in these countries. Safeguarding of "civil" plutonium facilities - especially reprocessing plants - still poses fundamental technical problems.

So long as plutonium remains as a constituent of spent reactor fuel, it is comparatively easy to keep track of. Intact fuel elements can be numbered and counted; either an element is present and accounted for, or it is not. Once the element is chopped up and dissolved, the accounting process becomes much more fuzzy at the edges. To begin with, even the actual amount of plutonium in a given fuel element is not easy to establish with precision. It depends on the operating history of the element within the reactor: its location in the core, its residence time, reactor power levels and changes, and other variables. Non-destructive assay techniques can be used to give more precise readings of plutonium content of particular elements; but they are not always employed, and even their precision is limited. Once the plutonium is in liquid solution and passing through the lengthy plumbing of a reprocessing plant it becomes significantly more difficult to measure how much there is, or where it is.

Until the mid-1970s the development of safeguards technologies concentrated on reactors themselves. Large-scale fuel-cycle facilities processing continuous quantities of concentrated fissile material posed a whole new category of distinctive and increasingly urgent problems. Safeguards experts designated "materials balance areas" within a facility, at which inventory could be taken. All the material leaving one area should be balanced by material arriving at the next. These extrapolative procedures suffered from obvious limitations, in particular the difficulty of measuring accurately the amount of fissile material actually present in a "materials balance area", and the uncertain time-lag occasioned by plant dynamics as materials flowed through it. Any discrepancy between "material in" and "material out" at a given inventory was "material unaccounted for", or MUF. A given inventory invariably produced a figure for MUF, which might be positive - more material in than out - or indeed negative - more material out than in. The limited accuracy with which the measurements could be made also led to a so-called "limit of error on MUF", or LEMUF: discrepancies between input and output might be within this limit of error, and could then be attributed merely to the shortcomings of the measurement techniques.

The cumulative effect of these limitations meant that safeguards could not assure to better than about plus or minus 1 per cent that all the plutonium going into a reprocessing plant was coming out of it again. For a plant of commercial size, with a nominal throughout of perhaps 1000 tonnes of spent fuel and accordingly perhaps 20 tonnes of plutonium per year, an uncertainty of 1 per cent would mean some 200 kgs of plutonium unaccounted for - enough for at least twenty bombs.

"Safeguards" as conventionally conceived therefore fell well short of any satisfactory guarantee that plutonium from such a plant was not being "diverted" for an uncivil application. (See also The Plutonium Business.) When the implications of this situation became clear, efforts got underway to devise more stringent measures that might meet the case. Beginning in the late 1970s, for instance, the US and Japanese authorities carried out at Japan's controversial Tokai Mura reprocessing plant an exercise that was given the acronyin TASTEX, for Tokai Applied Safeguards Trial Experiment. The exercise involved adding a variety of on-line equipment to the hardware of the plant, instrumenting it to track its inventory in much greater detail.

Whether such instrumentation can be added to existing and heavily contaminated plant is uncertain. In due course, for those reprocessing plants that may yet be built, some form of safeguards technology may be available that will provide sufficiently precise information to identify any diversion of plutonium from the "civil" output. This technical possibility nevertheless has to be set alongside two extra-technical considerations. In the first place, the owners and operators of the plant must consent at the outset to the installation of the safeguards technology. In the second place they must then continue to accept its presence and surveillance. All safeguarding activities of course take place only with the sufferance of the country being safeguarded; and any country can decide at any time that it will no longer accept safeguards, admit inspectors or allow surveillance. To be sure, if a country were to withdraw a facility from safeguards, the action would at once - at least in theory - trigger an international reaction. For many types of nuclear facility - for example light-water reactors - many months if not years would elapse before any military end could be served after the facility was withdrawn from safeguards - ample time for the application of international diplomatic or indeed military countermeasures.

For a reprocessing plant or a store of separated plutoniun, such would not be the case. If a country were to decide to use such a nominally civil plutonium facility for bombs, it could have the bombs ready to use within weeks if not days. Even though safeguards would be breached and the breach signalled, the safeguards could not give "timely warning" of the breach: warning in time to allow for appropriate and effective international countermeasures. Regardless of the application of safeguards, and no matter how reliable and foolproof they may be, the simple possession of separated plutonium or the means of separating it leaves a gaping hole in any barrier between the "peaceful atom" and its warlike sibling. A country may cross from one to the other before the international community can catch its breath.

Such is the inescapable corollary of insisting on the need to reprocess spent fuel and separate the plutonium it contains. Any country that has access to separated plutonium is ipso facto a so-called "near-nuclear" country in weapons terms. No sophistry should be allowed to obscure this grim fact. There is no technical solution to the problem of separated plutonium. But there is ample technical opportunity to make the problem even worse. Those countries determined to pursue and expand so-called "civil" plutonilln programs, with reprocessing, MOX thermal fuel and fast breeders, are leading the way to the abyss.

Is the Abyss Inevitable?

In a different context but with appropriate advice, the Welsh mountaineer Alwyn Rees once said "when you get to the edge of an abyss, the only progressive step you can take is backwards". For quite a few years that type of proliferation policy has been inconceivable. So long as policymakers believed in the inevitability of a global "plutonium economy", stopping the spread of nuclear weapons was indeed a hopeless cause - a cat out of a bag. In 1977, some overzealous pro-nuclear scientists at the US government's Oak Ridge National Laboratory went so far as to publish a report showing how easily a simple reprocessing plant could be built with small local industries, machine shop equipment, light construction techniques, ready funds, and a friendly and sympathetic populace willing to endure much radioactive exposure. While some simple - and very hazardous - reprocessing plants may exist in the world, their number can be counted on one hand. The likelihood of a plutonium economy is small; potential proliferators must rely on precarious political conditions, secrecy, appeals to national vanity, imports of vital equipment from western nations, and specious technical and economic arguments. In short, we should also not blind ourselves to the awesome success of nonproliferation since the first Hyde Park atomic pile: only five nations admittedly have nuclear weapons; only six are perched on the edge of that capability; and no non-weapons signatory of the NPT has acquired nuclear weapons.

The effort to stop the spread of nuclear weapons requires as non-discriminatory an approach to the NPT as possible. To begin with, the onus is very much on the superpowers - and their allies - to once and for all renounce national programs for plutonium use. As we have argued in prior chapters, the cost of that measure cannot be measured in harm to public health and security, or in money, but only in lost ego. With the advisable inclusion of weapons-grade uranium 235 (which was used in the Hiroshima bomb, but is rarely used today), such a policy would amount to a freeze on all fissile material production. This would apply equally to superpower weapons programs and energy efforts, and would be far more verifiable than a freeze on weapons or weapons tests because of the size of the multi-billion dollar reactors and reprocessing plants needed to produce weapons-grade plutonium. Producing weapons-grade uranium clandestinely - through enrichment by gaseous diffusion, gas centrifuge, or, prospectively, lasers - is expensive and obvious. Such a policy could be extended to all signatory nations of the NPT. In addition, controlling plutonium stocks might prove to be a better way to negotiate arms reductions than the current emphasis on particular weapons systems.

A similar strategy would involve the negotiation of a Comprehensive Test Ban Treaty, promised by past US and Soviet administrations. This would slow the technological development of "first strike" nuclear arsenals, demonstrate good faith on disarmament, and focus international attention on any new member of the "nuclear club".

The Non-Proliferation Treaty itself can be strengthened by resolutions among the member nations - a path far less controversial than actual amendments. The NPT, for example, could hold any signatory, including the superpowers, in violation for refusing to place its nuclear facilities under international safeguards. Nations that refused to do this would not be permitted nuclear assistance from any NPT signatory. As we described earlier, non-weapons nations could be prohibited from contributing to any nuclear weapons program - a possibility not foreseen in 1968 but very much present in 1985. Finally, aid for sustainable energy resource development must be bolstered. To be sure, this is not the nuclear assistance promised under the Treaty; but it complies with the Treaty's promise of low-cost energy far better than nuclear power has.

This combination of measures would very much retard, if not completely stop, the spread of nuclear weapons capability around the world. Like all effective foreign policy, it is dependent on a combination of common self-interest, public concern, moral suasion, and the less noble realities of power and leverage. So long as the superpowers are committed to the mutual escalation of weaponry, active (and at times subversive) competition for spheres of influence, plutonium production for ambiguous purposes, and retention of the policy option of a first nuclear strike, non-proliferation efforts will lack moral authority in the Third World and as much citizen support as they deserve worldwide.

Citizen groups could also pay more attention to non-proliferation. The subject has often been considered too wide-ranging for the environmental or anti-nuclear power movement; and irrelevant to the main goals of the freeze or peace movement. All can lobby aggressively on foreign aid programs, as well as national energy, radioactive waste, and security policy. Together with many governments, citizen groups can also lobby for nuclear free zones in Africa, Latin America (which has a limited one through the Treaty of Tlatelolco), Asia and the Pacific, Europe, and wherever else - including North America and the Soviet bloc - they have a chance. Success will be dependent on the evolution of rational policies in energy, Third World development, domestic nuclear policy, and arms control. This range of programs would have been considered radical and outrageous five or ten years ago. In 1985, they are beginning to look reasonable; a sign of how far we have come already.

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