THE NUCLEAR FUEL CYCLE
REPROCESSING AND RECYCLING FOR POWER

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WASHINGTON INTERNSHIPS FOR STUDENTS OF ENGINEERING
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About the Author

Peter Caracappa is a senior at Rensselaer Polytechnic Institute, pursuing a degree in Engineering Physics. This paper is the result of his research conducted through the Washington Internships for Students of Engineering during the summer of 1997. He was sponsored in this program by the American Nuclear Society.

WISE

The Washington Internships for Students of Engineering is a ten-week program for outstanding engineering students who are entering their final year of undergraduate study and display evidence of leadership skills and interest in public policy. The students spend the summer in Washington, DC learning how engineers contribute to public policy decisions on complex technological matters. Through frequent meetings and discussions with government officials and other policy-makers, students examine a variety of public policy issues. Each student completes a paper that analyzes specific issues of public policy that relate to science and technology. For information about the WISE program, contact WISE, attn.: Anne Hickox, 400 Commonwealth Dr., Warrendale, PA 15096-0001, or see the WISE World Wide Web Page at *http://www.ieee.org/wise*.

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EXECUTIVE SUMMARY

There is a worldwide debate over what to do at the back end of the nuclear fuel cycle. The United States has chosen to use fuel only once and bury all of its spent fuel as waste. Many other countries have chosen to reprocess and recycle this fuel as a power generating resource. Although those nations develop their own fuel cycle strategies, the United States, as a major political power and a supplier of nuclear material and technology, is able to influence those programs with its policies.

There are three major concerns in making the choice of a fuel cycle. One is the proliferation of nuclear weapons. The environmental impact of the operation of a fuel cycle, and the waste that it produces, is another major concern. Finally to many, economics is the key to any fuel cycle choices.

Until the late 1970s, the United States was on a direct path to developing a reprocessing economy. For a period of time, the entire effort was abandoned by executive order. By the time that order was lifted, opinion in this country shifted towards the once-through fuel cycle. Since 1982, the United States has been in search of a permanent repository for its nuclear waste, and is currently characterizing a site at Yucca Mountain in Nevada for that purpose.

The official position of the United States is not to support the reprocessing of spent fuel or the use of plutonium in commercial reactors throughout the world. Although it cannot control what countries decide to do with their own nuclear fuel, it has legislated that all nuclear material that originates in the United States is subject to US consent for its use. Consent rights must be obtained by the receiving country if it wishes to retransfer the material, enrich, reprocess, store, or alter the content of that material.

After twenty years of dedication only to the once-through fuel cycle, there is not sufficient justification for a sudden movement towards reprocessing in the United States. The Yucca Mountain project should continue to develop the site as a permanent repository. However, the United States needs to recognize that future conditions may warrant the use of that spent fuel in generating power. The design of Yucca Mountain should provide for accessibility to the storage area, so that the spent fuel may be retrieved.

In its international policy, the United States needs to recognize the legitimacy of the closed fuel cycle as a way to manage nuclear power, and should drop its unilateral requirement for consent rights. Instead, the United States should work within the international agreements that it is part of to provide for multilateral safeguarding of nuclear technology. The United States should support the formation of international compacts for reprocessing, to keep the number of sites engaged in reprocessing low, and it should support research for more accurately accounting for nuclear material within these facilities.

INTRODUCTION

THE NUCLEAR FUEL CYCLE

Every nuclear reactor operates on the same basic principle: atoms are split to generate power. However, there are many different methods by which this can be achieved. Through the nearly infinite variations on nuclear power, there are two primary methods of fueling a reactor.

In the "once-through" method, as its name suggests, the nuclear fuel is used only once. Uranium ore is mined from the earth, fabricated into fuel, and burned (meaning used to generate power) in a reactor. The primary fissile isotope of uranium is U-235, found naturally in a concentration of roughly 0.7 per cent, which the fuel enrichment process brings to a concentration of three to four per cent. The other most common isotope of uranium is U-238. In a nuclear reactor, U-238 will absorb a neutron and radioactively decay into a fissile element, in this case Plutonium-239. About 40 per cent of the heat energy in most once-through nuclear reactors comes from the fission of plutonium[1]. When that fuel can no longer sustain a nuclear reaction, it is removed and must be stored or buried.

Instead of burying spent fuel in the ground, another option is to reprocess and reuse the spent fuel in a "closed" fuel cycle. It is this "back end" of the fuel cycle that is a primary object of controversy in nuclear power policy. Within the closed fuel cycle, there are many different ways of reusing spent fuel, but they fall into two major forms. The most common of these is to refabricate spent fuel into mixed oxide fuel, or MOX, which is a mixture of plutonium oxide and uranium oxide, rather than only uranium oxide. The plutonium and the remaining uranium are extracted from the spent nuclear fuel to fabricate MOX fuel, but the rest of the elements in the spent fuel must still be disposed of. This waste consists of lower weight fission products and actinides, which are elements heavier than uranium. This fuel can be burned in the same type of reactor as once-through fuel. These are called thermal reactors because they use low speed neutrons in the nuclear reaction. The type of reactor that is most commonly loaded with MOX fuel is the Light Water Reactor, which is a type of thermal reactor. At present, MOX fuel can be reprocessed and reused two or three times before it is unable to sustain a nuclear reaction and must be disposed of.

Instead of fabricating fuel to be placed back into a thermal reactor, it could also be made for a fast reactor. The fast reactor gets its name from the use of fast neutrons rather than thermal neutrons in the nuclear reaction. The fast reactor was originally designed to produce more fuel than it consumed. "Breeding" fuel in this way gave this type of reactor the common name of "breeder reactor," but it is not necessary that the reactor be set up to breed fuel in this manner. The fast reactor cycle may also include actinides and U-238 tails, waste products from other cycles, as fuel.

CONCERNS AND OPINIONS

The concerns over these fuel cycle choices fall into three major areas. The first is the proliferation of nuclear weapons. The original purpose of extracting plutonium from spent fuel was to build nuclear weapons, and there is fear that commercial reprocessing could be adapted for that purpose as well. Another major concern is the impact on the environment. Nuclear power releases almost no pollutants to the air in its operation, but the problem of waste disposal and its impact on the environment over thousands of years has remained a serious debate. The final major concern over fuel cycle choice is economics. At $11 a pound, use of natural uranium is an economical choice for today, but the economics of tomorrow are subject to interpretation [2].

So, in the face of electric power deregulation, welfare reform, and a balanced budget amendment, is this a pressing issue in American politics? The United States has always had the advantage of plentiful energy resources. Despite the fact that nuclear power currently produces about twenty per cent of American electricity, the US could probably survive an eventual decline in nuclear power. In the short term, maintenance of the nuclear power industry is not of critical importance. However, many other nations of the world are not in the same situation as the United States, and have dedicated themselves to supporting a strong nuclear power industry, even in the short term [3]. In a global community, the United States is a major stakeholder, and its national interests are very much at stake.

Public support for reprocessing is something difficult to define. Only a very small portion of the public is aware of the possibility of reprocessing nuclear fuel to generate power. Most public opinions of reprocessing are hidden behind the public opinions of nuclear power as a whole. Though a comprehensive study has never been made, psychology suggests that the average American is more comfortable with the idea monitoring and utilizing spent nuclear fuel than burying it in the ground [4].

POLICY DEVELOPMENT

DOMESTIC POLICY DEVELOPMENT

In the early years of the development of nuclear power , all plans for power generation and waste disposal anticipated that it would become necessary to move to a closed fuel cycle[5]. At the time, the expected uranium resources of the earth were smaller than current estimates, and many more nuclear power plants were expected to be built, increasing the demand on uranium resources. Also, the comparative price of uranium mining and enrichment was considerably higher than it is today. The thermal reactors that were built as a first step in the development of nuclear technology that would lead to a closed fuel cycle. Early nuclear power plants were not built with large spent fuel pools, because it was assumed that the spent fuel would be sent away to be reprocessed [6].

This path was virtually unwavering until 1974. In that year, India conducted a test explosion a nuclear device. Until that time, the only nations with recognized stocks of nuclear weapons were the United States, the Soviet Union, the United Kingdom, France, and China. This new and sudden addition to the nuclear weapons states raised concerns around the world on nuclear proliferation.

Considering this concern, in conjunction with a report stating that a closed fuel cycle was not essential to the survival of nuclear power, President Carter in 1977 issued an Executive Order banning all development of spent fuel reprocessing and reprocessing technology. He further encouraged the other nuclear nations of the world to take up similar positions and not generate stockpiles of separated plutonium [7].

The Carter Decision was reversed by President Reagan in 1981, but the development of reprocessing continued to be discouraged by a lack of government support; Reagan felt that the market and the industry needed to take the lead in commercially developing fuel reprocessing [8].

A considerable drop in uranium prices, fueled by an increasing discovery and development of uranium mine sites and a slower than expected growth in uranium demand, discouraged the electric power utilities from returning to the path towards a fully closed fuel cycle[9]. The government furthered this discouragement in the passing of the Nuclear Waste Policy Act of 1982, which stated the Department of Energy would accept the spent nuclear fuel from the electric power utilities, starting January 31, 1998, and store it permanently[10]. At this point, the utilities no longer considered themselves to have a long term waste problem. The reality is that current estimates optimistically foresee that the DOE will be prepared to store spent fuel around 2010.

The laissez-faire attitude that Reagan wanted to take to the nuclear power industry was undermined by the passage of the Nuclear Waste Policy Act. It made the back end of the fuel cycle an issue of national policy, rather than strictly a decision of the individual utilities. The utilities became part of this strategy, and no longer have any incentive to be the leaders in finding new ways to utilize their spent fuel reserves [11].

CURRENT DOMESTIC POLICY CONCERNS

The United States has always enjoyed the freedom of a large amount of energy resources. Even after experiencing severe energy crises in the 1970s, promoting energy security has not remained a major political issue. The attitude towards nuclear fuel has remained that there are sufficient reserves, between those that are currently known and those that are still speculative, to fuel the US nuclear industry well into the next century [12]. The prevailing opinion in the US government is that, as long as it is not absolutely necessary, the US is not willing to consider the risks involved in reprocessing fuel as justified[13].

The environmental impact of the US policy decisions is focused currently on a single site: Yucca Mountain, Nevada. This is one of the sites that was under investigation under the direction of the Nuclear Waste Policy Act of 1982. The amendments to that act in 1987 made Yucca Mountain the sole site being investigated. This does not, however, place absolute assurance that Yucca Mountain will be the final repository for spent nuclear fuel. The viability assessment is still being completed by the DOE. If that report comes out positively, the site still requires final approval by the President. Then, after it is constructed, it must be licensed by the Nuclear Regulatory Commission. The current NRC requirements on a permanent repository (10 *CFR* 60) require that there must be "substantially complete" isolation from the environment for 300 years, and that all radioactive elements must be prevented from reaching the accessible environment for at least 1,000 years[14]. The EPA, which is developing its own standards for Yucca Mountain (with which the NRC licensing must also comply) is considering a compliance period of as long as 100,000 years[15].

The explicit economic effect of the US policy is derived from the NWPA of 1982. In this Act, the government levied a 1 mill (one tenth of a cent) per kilowatt-hour electric charge on electricity generated from nuclear power, for the purpose of using that money to fund the repository. A more implicit economic effect is felt by the utilities in the form of NRC licensing practices, and litigation from public or anti-nuclear groups that it might become subject to.

A great amount of mistrust has developed between the utilities and the government as a result of policies and how they are carried out. The fact that the Yucca Mountain project is well behind the legislated schedule is only the most high profile and dramatic example of the several times that the Department of Energy has failed to deliver on promises that it has made to the utilities[16]. The adversarial relationship that is perceived between the utilities and the NRC also builds a level of mistrust. The planning and building of a nuclear power plant is a long term investment, but the utilities confidence in using the current state of regulation to plan for the future has been eroded [17].

The current state of spent fuel lies somewhere between ownership by the nuclear power utilities, and ownership by the Department of Energy. The utilities are not prone to make long term investments in their spent fuel, because they have agreed that they will not be responsible for their spent fuel in the long term. The DOE is not likely to move quickly on investment in reprocessing because it has not yet accepted the spent fuel from the utilities, and because the President's position is that Yucca Mountain should be completed and be a demonstrated option before other methods of spent fuel management are considered[18]. The DOE considers reprocessing a wholly parallel option to the Yucca Mountain project, because some form of repository will be necessary for any fuel cycle, and reprocessing cannot be the entirety of the US spent fuel management strategy [19].

INTERNATIONAL POLICY DEVELOPMENT

Although fuel cycle choices are made individually, there are international agreements that help to insure the safety of those choices. The primary governing agreement over all use of nuclear technology is the Non-Proliferation Treaty, or NPT, which was extended indefinitely upon expiration in 1995. One accomplishment of the NPT was the authority it gave to the IAEA in its mission. One of the IAEA's primary missions is to give sufficient warning to the world community that there is a possibility that nuclear material has been diverted for weapons purposes [20]. It accomplishes this through sets of inspections that are carried out on the nuclear facilities of the member countries. For the European countries, there are additional and similar safeguards enacted by the European Atomic Energy Community, or EURATOM [21].

Within these international agreements, civilian fuel reprocessing is a global reality. There are operating reprocessing facilities in Britain, France, Belgium, and Japan. Additionally, Russia and China are pursuing the development of reprocessing facilities within their own countries. Germany and Switzerland, while not participating in the actual reprocessing of their spent fuel, contract with foreign companies, and load some of their reactors with MOX fuel. Only the United States, Sweden, and Finland have dedicated themselves solely to the strategy of geologic disposal of spent fuel. Most other countries have either “deferred” the decision on spent fuel management and are storing their spent fuel on an interim basis or they have chosen a mixed strategy where some nuclear material is reprocessed and some is meant to be stored permanently. [22].

The United States does not share the position that it is necessary to reprocess spent fuel. Additionally, though, the US “officially discourages civil use of plutonium in the [23] This is the position the President Clinton articulated in 1993 [24]. As an additional control over international activities, the Nuclear Regulatory Commission maintains strict oversight on all exports of nuclear material and technology potentially useful in the development of nuclear weapons.

The Nuclear Non-Proliferation Act (NNPA), passed in 1978, gave the US control over all nuclear material exported from this country through its entire lifetime. US approval has to be obtained for each transfer, enrichment, or reprocessing of all nuclear material originating in the United States, and for the storage or alteration in content of highly enriched uranium or plutonium derived from such materials. [25].

CURRENT INTERNATIONAL POLICY CONCERNS

Despite strong dedication to the once-through cycle and the example that the United States has tried to set, much of the rest of the world has not followed suit. Some of these countries consider the controls that the United States exercises under the NNPA to be unjustified impositions upon their fuel cycle choices, which they have heavily invested in[26]. Particularly in the Clinton Administration, approval for transfer or retransfer of materials for ultimate reprocessing has repeatedly been held up and granted begrudgingly[27]. There have been times that the United States has allowed more flexibility under the NNPA, such as a compromise that was worked out with Japan under President Reagan, which allowed US material to be used in the development of the Japanese reprocessing program. However, even with this agreement, there were Congressional attempts to block or delay the transfer in the form of banning the shipment of nuclear material by air, and requiring DOE studies of the safety of sea shipment [28]. This seriously undermines the reliability of the United States as a supplier of nuclear material in the eyes of these other countries[29]. By not recognizing the legitimacy of the closed fuel cycle in other nations, the US is in danger of losing its influence in the global nuclear community among nations that are going to participate in reprocessing, regardless of US support [30].

Bringing conclusion to the geologic storage development project may also add some validity to the US position in the fuel cycle debate. Many countries have expressed difficulty in accepting the option of strict geologic storage from the United States because it has not yet sufficiently demonstrated its ability to deal with the associated problems. Most of these countries have plans for their own geologic repository, but are counting on their reprocessing efforts to allow them to build these repositories on a smaller scale, in both volume and lifetime, than the United States plan. Because they are making use of their spent fuel, these countries are also not rushing to complete their repositories. Many of their plans do not call for a repository to open for another thirty to fifty years [31]. On the short them, their temporary storage facilities are sufficient for storing spent fuel.

In order to effectively implement a fuel reprocessing strategy, the issue of security of explosive-capable materials must be addressed. It is a significant technological challenge to build an explosive device of any yield from the plutonium that is in either spent fuel or reprocessed fuel, but the IAEA has taken the position that all plutonium is dangerous enough to need safeguards[32]. Although the safeguards applied to these facilities have thus far been apparently effective, there are those that remain concerned over the limitations of these safeguards, and their effectiveness in deterring weapons proliferation.

The economics of the closed fuel cycle are also in dispute. An April 1994 study done by the OECD Nuclear Energy Agency calculates the costs of their reprocessing to be in the range of seven to fourteen per cent higher per kilowatt hour than the open fuel cycle[33]. Some criticize the OECD study based partly on the fact that most of its economic information was provided by BNFL and COGEMA, two companies in the business of reprocessing, and the method of the developing those costs are not well explained, and cited as proprietary information[34]. However, another US study has calculated the overall fuel cycle cost for a reprocessing system to be as much as 44 percent higher than for once-through[35]. In support of their programs, these countries contend that most of the costs involved in their system of reprocessing have already been incurred, while the costs involved in building a permanent repository lie in the future, so they do not share the same economic conditions with the US program[36].

Much of this contradiction comes from the method of economic analysis used to determine costs over such a long period of time. Available space precludes a detailed explanation of the methods of economic analysis, but in summary, two major methods are used. One common method is the discounted cash flow method, which is inherently biased towards disposal. In this method, future expenses are reduced to almost negligible amounts as compared to current capital investment. For instance, in terms of present value, one dollar now may be valued higher than one hundred dollars sixty years from now. The OECD study, however, used a "levelized" cost method, and the economic advantage in the once-through cycle was calculated to be far less significant [37].

One area that will have a great effect on the future of nuclear energy as a whole, and on reprocessing especially, is what the future energy needs of the United States and the world actually turn out to be. In this country, the energy requirements have been growing much more slowly than predicted. In the 1970s, scientists and economists were predicting that the US would increase its energy use at a rate of about seven percent a year, whereas the actual growth has been around two to there percent a year [38]. A study, done by the IAEA proposes a couple of possibilities, including one in which the generation of nuclear power in the world drops off past about 2040. The predictions of nuclear capacity in the world in 2050 ranges from 333 GW(e) in the low variant, to 1805 GW(e) in the high variant[39]. Even within the nuclear industry, there is no clear idea as to what will be needed in the future.

POLICY ALTERNATIVES

The US policy exists on two faces: the international and the domestic. Although the decisions of these two different areas are not completely independent, for the sake of simplicity, they will be considered separately.

DOMESTIC POLICY CHOICES AND EVALUATION CRITERIA

The United States has three major choices in the management of its spent fuel. One is the option that it is currently pursuing, which entails building a permanent repository for spent nuclear fuel. Another option would be to move to reprocess this fuel and fabricate it into MOX. A third option would be the development of commercial fast reactors for power generation. These three options are not entirely independent. For instance, if the United States moves to reprocessing fuel, it will still need some type of repository for waste storage, and if the US develops commercial fast reactors, they will likely work in conjunction with either MOX or once-through thermal reactors. However, to analyze the policy issues involved, they can be considered separately, as if each was the primary focus of the US nuclear fuel cycle.

The criteria for evaluation of these different options fall into several major areas. One leading criterion, as is often the case, is economic impact. The government has a major concern for the cost, as it will likely assume control of the industry's spent nuclear fuel in the near future. However, the impact on the nuclear power industry, as well as the possibility of returning some of the burden of choice to it, is a portion of this impact.

In the last several years, the government has tended to base a lot of its decision making on environmentalism. It would make sense that environmental impact would play a major part in the investment of a nuclear fuel cycle. The primary area of environmental impact is the waste that is generated by the cycle. Volume, toxicity, and lifetime of waste are the major areas of concern. In addition to the waste generated, there is also an issue of the risk to the environment through the process itself.

The leading factor in the US policy of the last twenty years has been the concern over international safety and non-proliferation of nuclear weapons. The question becomes one of the degree of risk involved in the use of a particular cycle. The two major areas of consideration are how difficult it would be to divert nuclear material from that type of processes, and then how difficult it would be to fashion that material into a nuclear weapon.

The more distant future is often overlooked when trying to make policies that are acceptable to the people of the present. However, the energy needs of the future are inherently uncertain. There are possibilities, more or less extreme, that will require that nuclear power be more heavily utilized. The world is in a constant state of innovation, so there is also the possibility that nuclear power will be less necessary in the future. How these systems adapt and fit into the different situations of the future is an area of concern.

Lastly, the acceptability of these options is a point for evaluation. A concept might make sense from every logical standpoint, but if it cannot find acceptance in Congress, it does not have a future. The government tends to put its own priorities on these different criteria, so the ability of the government to take action on an item must be considered. At the highest level, though, the members of Congress answer to their constituents, and public opinion and public acceptability become a major factor to acceptability.

Geologic Storage

The funding structure for geologic disposal is already in place. The nuclear waste fees levied on the utilities, and interest, has totaled about $10 billion, of which $5 billion has been appropriated to date to the disposal of nuclear waste. Additionally, there are about $2 billion in outstanding payments for nuclear waste generated before 1983 [40]. A FY1995 report from the DOE projects the total costs of the repository, until the repository is ultimately sealed to the outside (expected around 2071) to be $33 billion [41]. The costs to utilities for this option are fairly well known. At the maximum, the utilities will continue to pay the 1 mill per kWh that is part of the current law. Litigation and legislation may make adjustments to that payment after the 1998 deadline, possibly putting payments into escrow until spent fuel is accepted, or making the fees paid directly related to the amount of funding appropriated to the DOE for the disposal project [42].

The environmental impact of the Yucca Mountain storage site is part of the current viability assessment that the DOE is pursuing. Current legislation may affect the way this impact is determined. The Energy Policy Act of 1992 directed the EPA to develop standards specifically for the Yucca Mountain site. EPA has been developing release limits for the repository, whereas the new amendments to the NWPA direct those standards to be risk based (in the case of Senate 104), or dose based (in the case of House Resolution 1270). The environmental risk involved in this option consists mostly of the uncertainty in predicting geologic activity for 10,000 years into the future. Additionally, the repository is under the threat of future human intrusion. The National Academy of Sciences was able to find no scientific basis to predict human behavior over thousands of years, so this risk is difficult to quantify [43].

Geologic storage is generally considered the safest from a non-proliferation standpoint. This is due to the relatively intense levels of heat and radioactivity that are present in fuel that is initially removed from a reactor core. Therefore, even though there is a significant quantity of fissile plutonium in spent fuel, it is considered too difficult to clandestinely separate to form a nuclear weapon. However, spent fuel will cool over time, so the risk of proliferation is not eliminated, but is rather deferred to two or three generations in the future [44]. After about fifty years, the separation of plutonium from spent fuel becomes a much simpler task for an aggressor nation or a renegade group, while the percentage of that plutonium that is fissile remains approximately the same [45].

As fuel is burned in a reactor, some of the U-238 will become Pu-239. That Pu-239 will either fission or will absorb additional neutrons to become heavier and less fissile isotopes of plutonium. The first plutonium created will all be the fissile isotope, Pu-239. As the reaction continues, the proportion of the plutonium that is fissile will slowly decrease. The proportion of plutonium that is fissile correlates to its usefulness in nuclear weapons. At the time of a normal discharge, about 70 per cent of the plutonium is fissile. "Bomb-Grade" plutonium is considered to be plutonium that is 90 per cent or more fissile, though it may be possible to make bombs with lower proportions. Although a fuel rod in an operating reactor is an almost non-existent proliferation threat, should that rod be discharged before the normal burnup time is complete, it may be a significant threat. One-third of the way through a normal burnup period, the proportion of plutonium that is fissile would still be considered bomb-grade [46].

Spent fuel is not going anywhere for thousands of years. This has both an up side and a down side. It is largely dependent upon the future trends of nuclear energy. If the nuclear power industry continues as it is, or eventually declines, the world is left with a pile of waste material. As it is currently designed, when and if the Yucca Mountain site opens, civilian spent fuel and military high level waste (which is also destined for the permanent repository) that is in existence at that time will more than fill it [47].

On the positive side, if future nuclear power trends lead to the expansion of fuel reprocessing, a great deal of material will be usable, and if the Department of Energy plans for it, relatively accessible. Legislation that passed the Senate in April of 1997 provided for the possibility that the Department of Energy could seek a license for Yucca Mountain to permit emplacement of waste in the repository on a retrievable basis [48]. If the United States does remove spent fuel from Yucca Mountain to reuse it, there will already be an operating facility for the storage of those waste products. Opponents argue that this would require the United States to indefinitely monitor the repository rather than seal it permanently. Regardless, it may be necessary to indefinitely monitor storage facilities to assure compliance with IAEA safeguards [49].

This is the option with the legislative momentum to most easily continue. The Congress and the Administration have repeatedly stated that long term storage in Yucca Mountain is their ultimate goal. The public has a desire for a spent fuel disposition solution, but, as is evidenced by the continued opposition to the Yucca Mountain project by the state of Nevada, the classic "Not in My Backyard" attitude is prevalent in this issue.

REPROCESSING FOR MOX FUEL

Though the timetable is currently in dispute, the Department of Energy will eventually become responsible for all the spent nuclear fuel in the United States. That leaves the decision on reprocessing the spent fuel relatively strongly in the hands of the DOE. From a strictly economic standpoint, there is currently no advantage in reprocessing spent fuel. The Nuclear Waste Trust Fund, established by the NWPA provides only for the construction of a permanent repository. The DOE would have to obtain additional appropriations for a reprocessing program, which would not be offset by income from the utilities. On the other hand, that policy could be adjusted by act of Congress, as was considered in the original form of S. 104. It allowed money from the funds collected for the repository to be applied to the costs of reprocessing fuel, under certain conditions. If a power plant is facing the possibility of shutting down due to lack of spent fuel pool storage, they could receive money from the waste disposal fund to pay for their reprocessing. This is essentially an "out" to allow the utilities to deal with the delays in the opening of a repository. However, this clause was dropped very early in the consideration of S. 104 due to lack of support [50].

The nuclear power utilities have all chosen to participate in the national choices for the back-end of the fuel cycle. By paying for geologic storage, they have no real economic incentive to also move to begin reprocessing fuel. However, if the United

States chose to modify its spent fuel strategy and began to reprocess the fuel that it accepted from the utilities, those utilities may choose to load their reactors with that fuel. If a power plant wanted to move to load its core with 30 per cent MOX fuel, this could be done with minimal capital investment.

According to COGEMA, the French reprocessing company, the purpose of fuel reprocessing is two-fold: to reclaim useable plutonium and uranium from spent fuel, and to reduce the toxicity (volume and radiotoxicity) of nuclear waste to as low as reasonably achievable[51]. COGEMA expects the volume of waste from reprocessing to be one-fifth that of the open fuel cycle[52]. This waste consists primarily of fission products, which have a much shorter radioactive lifetime than spent fuel. However, small amounts of higher actinides are present, which have lifetimes on the same order as plutonium, which is the primary component in the long lifetime of spent fuel. Research is underway to prepare for burning these actinides to generate power, and to be able to recycle spent fuel more than two or three times, further reducing the need for extremely long term storage [53].

The environmental risk associated with the recycling process itself it low. A reprocessing plant is different from a power reactor in that it operates at low temperature and pressure, and uses static processes lasting for a long time [54]. The operating reprocessing plants in France, for instance, have been monitoring the release to the environment of radioactive elements for many years. The activity of these releases has been on a steady decline. All of the measured man-made radioactivity contribution is below the natural radioactive background level.

The real level of non-proliferation risk in MOX fabrication is one open to debate. Since MOX is made from spent fuel, the proportion of plutonium in a MOX fuel rod that is fissile is already around 70 per cent. As the MOX fuel is burned, that proportion decreases even further, so that fuel that is prematurely discharged is even less of a proliferation threat[55].

The biggest concern is that, in the recycling process, plutonium is separated from the fission products, which is seen as the greatest barrier to immediately utilizing spent fuel for nuclear weapons usage. Additionally, the MOX fuel pellets are seen as more portable than spent fuel, and would be easier to divert [56]. The reprocessing companies have instituted additional security measures to try to counteract these inherent uncertainties. BNFL has automated a great deal of its fabrication process, trying to eliminate as much human contact with the fuel as possible. For stages of the process where the plutonium content is not directly measurable, more indirect methods of accounting are utilized. Although there is a relatively high level of uncertainty in this method (perhaps as high as 20 per cent) it is used in conjunction with traditional security measures, and is considered sufficient by the reprocessing companies [57,58]. Standard practice at any nuclear facility is to check those leaving the site for radioactive contamination. It is not as simple walking out with a MOX pellet in a briefcase or a pocket. Commercial reprocessing in the United States would be expected to develop the same types of safeguards for its facilities.

Although reserves of natural uranium are plentiful enough for our current needs, natural uranium is as much a non-renewable resource as are fossil fuels. Recycling spent nuclear fuel slows the rate of depletion of those resources. Existing Light Water Reactors can incorporate 30% MOX with little or no modification in design [59]. Research is ongoing in some countries in an effort to load reactors with 100% MOX [60].

Since any effort to begin reprocessing in the Untied States will likely come from the DOE and not the utilities, that decision can be as much political as it is economic. The current administration is strongly against fuel reprocessing, and the prevailing attitude in the Congress is the same. However, there are those in the Congress that do not have the same feeling. Most prominently, Senator Murkowski, Chair of the Senate Committee on Energy and Natural Resources, has stated that he recognizes the closed fuel cycle as a legitimate approach to spent fuel management [61]. The biggest concern, though, remains the fear of nuclear proliferation from the support of the MOX cycle. There will need to be significantly greater assurances that a national or sub-national group would be unable to clandestinely divert plutonium before reprocessing of US fuel will become supportable in either the Executive or Legislative branches.

REPROCESSING FOR FAST REACTORS

Fast reactors also can use reprocessed fuel to generate power. Moving to this type of reactor would require more economic investment than using MOX fuel, as the technology for operating fast reactors on a commercial scale is still in development. Until 1993, when funding was eliminated, the United States had invested extensively in the development of a fast reactor commercial prototype. The most recent step in that development was a project at Argonne National Labs, known as the Integral Fast Reactor, or IFR. There are programs for developing fast reactor technology in other countries, but they, too, are feeling the effects of the economics of nuclear power over the last twenty years. The French have two fast reactor projects, called Phenix and Superphenix. Both of these projects have been on and off line over the years, and the new French government has expressed that they will once again shut down operation of the programs. The Japanese have a demonstration reactor and are progressing towards a commercial reactor, although the timetable for operation has been delayed significantly. Russia actually has a small fast reactor that is operating commercially, although lack of monetary support has all but eliminated its plans to build three more fast reactors [62]. Although the technology to harness the fast neutron reactions exists, government investment is needed to make it a commercially viable option.

On the other side of the coin, the fast reactor solves some of the problems with the once-through and the MOX cycles. Just as the MOX cycle reuses the plutonium and uranium from spent fuel, the fast reactor cycle is able to use the other actinides, as well as the non-fissile isotopes of uranium and plutonium, to generate power. The high level waste consists almost solely of fission products, so spent fuel storage becomes a simpler problem, as the storage facility does not need to last as long [63].

The IFR project was designed to minimize both the environmental and the proliferation risks in the fast reactor technology. The environmental impact of recycling fuel for a fast reactor is similar to that for MOX fuel fabrication and use. The major innovation in the IFR project was fueling the reactor with a metal fuel rather than an oxide fuel, which was designed to be recycled in a facility on the same site as the actual reactor. From an environmental standpoint, this virtually eliminates the concerns over the safety of transportation of nuclear material. Also, the IFR can burn the actinides from light water reactors and from its own reaction, which further relaxes the needs of the waste storage.

The unique metal fuel of the IFR also overcomes some of the proliferation concerns connected with the fast reactor. Rather than pellets of metal oxide, the fuel is an alloy containing pure plutonium. Even though metal plutonium may be more useful in generating a nuclear weapon, no technology currently exists for separating pure plutonium[64].

The fast reactor cycle was originally designed to produce more fuel than it consumed, or "breed" fuel. The IFR is also designed to consume plutonium fuel rather than produce it[65]. Fabricating fuel in the same facility as the reactor also serves to reduce the proliferation threat.[66]. Opponents to the IFR argue that the reactor can be easily adapted to produce plutonium, so the IFR-like reactors still pose a proliferation threat [67].

From very early on in development of nuclear power, the fast reactor was seen as the ultimate endpoint of nuclear reactors. That is because it turns an extensive supply of energy into an almost limitless supply of energy. Fast reactors could supply the world's energy into the foreseeable future. Additionally, if new preferred methods of power generation, such as fusion energy, become a reality in the future, the fast reactor could continue to be used to reduce the remaining stockpiles of plutonium and heavy elements, until it is eventually phased out.

Despite all the innovations that were developed with the IFR, reprocessing of fuel even for this purpose suffers the same political opposition as recycling for MOX. With the severe budget constraints that the federal government is continuing to find itself under, strong support for the IFR or other fast reactor projects will be difficult to justify in Congress.

US International Policy Choices

Fuel cycle choices are made by individual countries, and there is little that the United States can do to directly affect how another country operates its nuclear power industry. But as long as the Untied States is a major supplier of nuclear material and technology, it can exert a degree of influence through the types of controls derived from the Nuclear Non-Proliferation Act. The attitude that the United States maintains towards other countries' reprocessing programs largely affects how it exercises these powers.

The current policy of discouraging international development of fuel reprocessing has had little or no noticeable effect. If anything, it had caused other countries to expand their nuclear power programs, including their reprocessing programs, because they do not feel that they can count on the reliably of the United States as a supplier of nuclear technology. Taken to the extreme, this could cause an isolation of the United States in global nuclear energy development, which runs very much counter to the United States desire to insure non-proliferation through responsible use of nuclear power [68].

Another option is to take the opposite approach, and fully accept the development of reprocessing facilities. This may also be an equally dangerous path to follow. So far, the only countries that are actually reprocessing their fuel are those that are popularly considered "responsible" in their use of nuclear power and their dedication to non-proliferation. The criticism of the Japanese reprocessing program was not as much the fear that Japan would start to develop nuclear weapons, but that countries such as South Korea would look to Japan as a model [69]. Those countries may not have the same incentive to maintain strict controls over the fuel reprocessing as Japan, and may have greater tendency to use the technology to build nuclear weapons. The IAEA is designed to reduce this threat, but its ability to do so has been criticized on a couple of fronts. First of all, the IAEA has been operating on a limited budget, and would have a difficult time adequately inspecting a significant number of facilities [70]. Also, a study done by the Center for International Studies at the Massachusetts Institute of Technology suggests that the level of uncertainty in measurement from a large reprocessing facility might be enough to hide a diversion of a significant quantity of plutonium [71]. The constant threat of the Cold War is gone, but there are still aggressive nations in the world, which might try to take advantage of open access to reprocessing technology. The IAEA would need to significantly improve its accounting practices to make assurances against diversion of nuclear material in a country that may not be as cooperative as those that are currently operating reprocessing facilities.

The third option is a mix of these two attitudes. The United States could recognize the legitimacy of the closed fuel cycle, but limit its support for the spread of that technology. There is currently very little cooperation between countries in the policies of the back end of the nuclear fuel cycle. If fuel were reprocessed in a limited number of specified countries by way of international compact, it would be much easier to safeguard the nuclear material. The IAEA would be able to dedicate its monitoring efforts to a few centralized facilities, instead of many smaller ones all over the world. The material returned to the member nations would be no more useful for constructing weapons than the material that they currently possesses.

The corollary concern with such an international system of reprocessing involves the shipping of nuclear material around the globe. Intra- and inter-continental nuclear shipments have been taking place for several years, without incident [72,73]. The primary shipment fleet is owned and operated by BNFL. Despite the impeccable track record, opponents argue that the risks involved with shipment cannot be completely eliminated [74].

The waste that is generated at a central facility would a lso have to be dealt with in the international community. Companies that currently reprocess fuel return the waste products to the contract holder for disposal [75]. This practice could easily be adopted in such an international agreement. It is considered entirely feasible for such a group of countries to dispose of there waste in a common disposal facility [76]. Central storage facilities would likewise be easier to manage and monitor, and provide less impact on the environment than many smaller facilities.

To achieve acceptability in the US government, there must be a further level of assurance that nuclear material can be adequately accounted for. Anti-reprocessing activists will continue to be able to argue that reprocessing has an unacceptable risk of proliferation until it can be definitively shown to be otherwise. Any change in the US support for fuel reprocessing would need to include support for safety systems research.

RECOMMENDATIONS

The reprocessing of spent nuclear fuel is a global reality. The US policy discouraging the civilian use of plutonium in power generation has not accomplished its goal. By maintaining this position in the current international climate, the US is in danger of losing its ability to affect global nuclear energy policy entirely.

First of all, the United States needs to recognize the legitimacy of the decision to move to a closed fuel cycle that some countries have chosen. To that end, consent rights should be eliminated from the Nuclear Non-Proliferation Act. This is not to say that the Unites States should pay no heed to non-proliferation concerns in granting of export licenses, but that a country with sufficient non-proliferation credentials to obtain an export license should be responsible enough to deal with that material as it sees fit. The United States should not try to maintain control of US-origin material in another country.

Instead, the non-proliferation efforts of the United States should be directed towards improving the effectiveness of the IAEA at safeguarding against the diversion of nuclear material. The United States should encourage countries interested in reprocessing their spent fuel to enter into international compacts and have their spent fuel reprocessed at centralized locations. Disposal should also take place through these compacts, through one or more central repositories.

Centralized facilities will allow the IAEA to focus its plutonium safeguards on only a few facilities, rather than all around the world. The economy of scale would dictate that it would be less costly to reprocess in a few large facilities, rather than in many smaller ones. Central disposal facilities should also be purused to reduce the environmental impact that would be caused by many smaller repositories.

The United States must work with the IAEA and its other member nations to improve methods of accounting for nuclear material. Larger reprocessing facilities raise the concern of larger amounts of lost plutonium to be hidden within statistical uncertainty in measurement. Improving these measurements will help to legitimize the non-proliferation credentials of these facilities.

Recognizing the legitimacy of the closed fuel cycle and e ncouraging international compacts does not necessarily imply that they United States needs to move its own fuel cycle strategy to a closed cycle. In fact, the economic and political climate in the United States discourages that course of action. The prevailing attitudes in the government nearly force the United States into completing the development of repository at Yucca Mountain. It cannot abandon this course of action.

What the United States does need to do is prepare for the possibility that it may want to move to a closed fuel cycle in the future. Rather than simply allow the Secretary of Energy the option of licensing Yucca Mountain as a long term retrievable facility, the Secretary should be directed to develop a plan for making the spent fuel in Yucca Mountain accessible to retrieval for future use.

The United States enjoys a secure supply of energy, and is secure in the avoidance of nuclear war. However, the policies of the United States do not provide for either of these to be maintained in the long term. The United States needs see itself as an equal member in the international community, and work with its neighbors to maintain the safety of the world, and it needs to begin to consider how its decisions of today may affect its security in the future.

KEY TO ABBREVIATIONS

CFR	Code of Federal Regulations
DOE	Department of Energy
EPA	Environmental Protection Agency
EURATOM	European Atomic Energy Community
IAEA	International Atomic Energy Agency
IFR	Integral Fast Reactor
MOX	Mixed Oxide
NNPA	Nuclear Non-Proliferation Act
NPT	Non-Proliferation Treaty
NRC	Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act

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