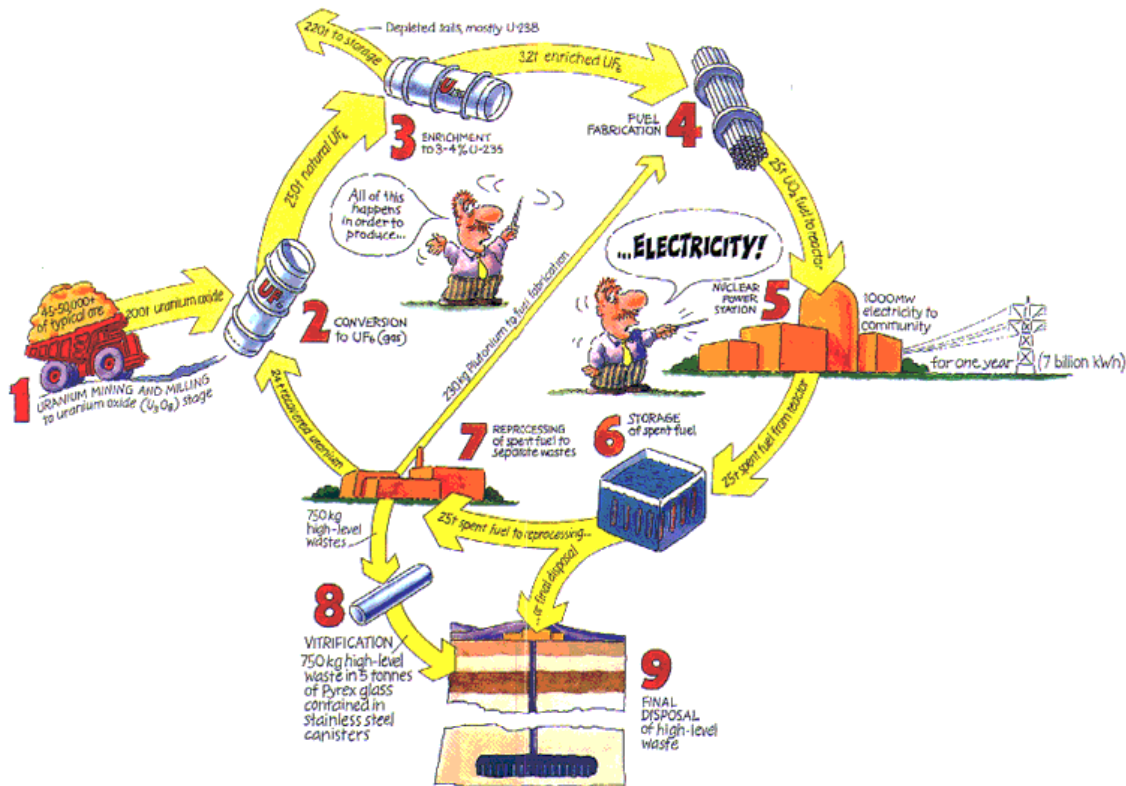


The Yucca Mountain Repository and the Future of Reprocessing



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Glossary and Acronyms

BANANA – Build Absolutely Nothing Anywhere Near Anybody

BNFL – British Nuclear Fuels Limited

COGEMA – A French nuclear fuels company

DOD – Department of Defense

DOE – Department of Energy

EPA – Environmental Protection Agency

HEU – Highly Enriched Uranium – Enriched uranium fuel with above 20% by weight ²³⁵U

LEU – Low Enriched Uranium – U fuel enriched less than 20% by weight ²³⁵U

LWR – Light Water Reactor – A nuclear reactor that uses natural water as both coolant and moderator

MOX – Mixed Oxide fuel – a substitute for enriched uranium fuel consisting of a mixture of plutonium, uranium and minor

Actinides

MGR– Monitored Geologic Repository – The storage of spent fuel and other nuclear materials in such a way that they are

observed at all times as well as easily retrievable, yet still isolated deep in the geologic repository..

MTHM – Metrics Tons Heavy Metal – A measurement by weight of spent nuclear fuel.

NIMBY – Not In My BackYard

NRC – Nuclear Regulatory Commission

NWPA 1982– Nuclear Waste Policy Act of 1982

NWPAA 1987 – Nuclear Waste Policy Amendment Act of 1987

OCRWM – Office of Civilian Radioactive Waste Management

Pu – Plutonium

PUREX – The basic process of chemical separation of spent fuel from its fission products in a series of chemical steps.

RAR – Reasonably Assured Resources – Those uranium resources that are reasonably likely to be found in the near term

SNF – Spent Nuclear Fuel

SWU – Separative Work Unit – A measurement of the amount of energy/work that must be put into U fuel to enrich it.

TRU – Transuranic materials – usually referring to Pu, Am, Np, Cm et al.

U – Uranium

UREX – A more modern iteration of PUREX, which eliminates any pure plutonium streams from the process

USED – United States Enrichment Co.

USG – United States Government

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About The Author

Simon Lobdell was educated originally at Central Catholic High School in Pittsburgh Pa. After accepting a scholarship to the Pennsylvania State University Shreyer Honors College, he entered the school of engineering. He immediately became interested in energy issues and specifically nuclear energy. He has published a paper on gamma ray collimators and has attended several technical conferences. His main interests focus on the advanced closed fuel cycle concepts proposed by the DOE. Aside from nuclear fuel cycles and energy policy, the ideas of Aldo Leopold and E. F. Schumacher have caused him to be deeply interested in international development and environmental ethics.

He intends to continue on in Engineering and Public Policy for graduate studies. He will also be applying for law school at Lewis and Clark University for Environmental law. Simon plans to graduate May 2003 from Penn State.

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About WISE

Washington Internships for Students of Engineering is a multidisciplinary program that brings engineering students together in Washington DC for the summer. The interns spend their time attending meetings with different government officials and NGO representatives. The goal is that these students will become familiar with the Washington DC environment as well as the complexity of public policy decision-making. The final result is that the interns write a paper concerning a policy issue of their choice. The following paper is the product of this effort.

Executive summary

The following paper will give a broad analysis of both the history and the possible future of reprocessing in the United States. The US nuclear fuel cycle, as dictated by the NWPA of 1982, will currently be an open cycle with the final site of disposition being at Yucca Mountain. The analysis will focus specifically on the Yucca Mountain repository and the implications it will have on the future of advanced fuel cycles involving reprocessing. There are some basic assumptions that will be made throughout the analysis.

First, the US will build the Yucca Mountain repository site. Although there is some possibility that Nevada will legally halt the process, it appears likely that the facility will be operational by 2020 and possibly earlier.

Second, no major changes to the US nuclear fuel cycle will be instituted (e.g. transmutation, laser enrichment, etc.) before the US again considers reprocessing.

Third, it is assumed that before any US reprocessing plant treats any commercial Spent Nuclear Fuel (SNF), the Yucca Mountain Facility will be operational and at least partially loaded.

Finally, there will be significant growth in the coming decades in the generation of nuclear energy in the U.S. Record high support for the nuclear industry was recorded in recent surveys showing an average of 66% of US adults nationwide supported the use of nuclear energy as a form of electric generation.²³ Furthermore, the IAEA predicts a 7% capacity increase worldwide in nuclear generating capacity by 2010.¹⁴

The ultimate observations gleaned from this report are as follows:

1. The viability of a reprocessing plant should be judged based on its ability to optimize the *entire* fuel cycle rather than just the front or back end.
2. If feasible, the proposed plant should benefit from any net savings of storage of HLW through payment from the Yucca account to the reprocessing plant. This transfer should be used to amortize the plant's capital investment and operational costs. This payment should only come from a quantifiable savings for the Yucca Mountain repository to avoid the possibility of being considered a subsidy.
3. The Yucca Mountain site should be studied as a principle site for a reprocessing plant.
4. Reprocessing should not be considered as an alternative to U fuel at this time. Moreover, it is unlikely any commercial reprocessing plant will be built in the US for at least 30 years unless the

savings from observation (2) are large in comparison to proposed plant costs.

The choice of 30 years is based on expert testimony and the general status of the international uranium market. Currently, the US fuel profile relies almost fully on rich foreign suppliers for its feedstock. These supplies are likely to remain relatively stable for up to ten years. Furthermore, Russian Highly Enriched Uranium (HEU) will depress the market for as much as 30 years, preventing any large price increase during this time period. Some experts¹⁹ say that when uranium fuel becomes 4 to 5 times as expensive as it is now, Mixed Oxide (MOX) fuel will be competitive. This could be many decades away. Others²⁷ say uranium will need to be as much as ten times as expensive. Current estimates predict that the addition of reprocessing to the nuclear fuel cycle would increase the entire cost of the cycle by 38%.²⁴ This condition will most likely continue throughout the next 30 years due to the influence of Russian HEU unless there is a large increase in the demand for nuclear energy.

On the other hand, any savings incurred from disposition of a lower volume of waste due to reprocessing, if treated as a service to Yucca Mountain *as well as* a method to produce MOX, could offset the cost of the plant and cause it to be implemented before it might otherwise be economically feasible. This will be justified if, due to market conditions, there is a net optimization of the fuel cycle.

Various possible savings for Yucca exist. The example of the drip shield savings due to volume reduction caused by reprocessing is explored. These shields provide protection on the timescale of 10,000 years. However, HLW is both more compact than SNF and only dangerous for 1000 years. Titanium drip shields added as much as 7 billion dollars to the latest estimates for Yucca's life cycle costs. These costs could be reduced or completely eliminated by the use of reprocessing. A full analysis of the effects of storage of HLW in place of untreated SNF would be necessary to assess whether a real savings exists. However, such an analysis would require a final design as well as reliable cost estimate for Yucca Mountain.

It is highly unlikely that there will be major political support for any deployment of a commercial reprocessing facility until significant pressure is placed upon the entities that benefit from nuclear power to ensure fuel supply and prices. The final point of interest is that the regulatory structure in the US capable of dealing with a modern reprocessing facility would require significant review if it were to be used in the future but this review is not warranted at this time.

Reprocessing is especially an interesting prospect for the Yucca site itself. The US has not pursued reprocessing for many years. More and more, however, it is a matter of public debate. To support the debate, the Yucca Mountain site is being built, loaded and *not backfilled for as much as 300 years*, implying that the option to reprocess remains open. Due to the high cost of transportation and the centralization of US Spent Nuclear Fuel (SNF) at Yucca, it is unlikely that the fuel will be moved again. Thus, in the scenario where there is significant growth of the nuclear industry in the coming decades, Yucca could, in essence, be a mine for uranium and plutonium. The cost of recovery of the material is the cost of reprocessing it. In the long term, it is likely that the SNF therein will become economically viable resources making Yucca a valid site for a reprocessing facility.

Although further work is needed, it is concluded that the US needs to maintain a solid technological base to be able to develop domestic reprocessing capacity as well as meet its non-proliferation goals.^{21, 22}

Chapter 1: Introduction and the Yucca Site

1.1 US Nuclear Waste and the Nuclear Fuel Cycle

During the Cold War, hundreds of tons of weapons grade plutonium were separated at the Hanford and other Department of Defense (DOD) sites leaving millions of gallons of highly radioactive and toxic waste at the sites. The majority of the nation's highly radioactive material though, has been produced by the commercial nuclear power industry. The DOE's obligation to "deal" with this material has become one of its primary missions as well as great stumbling blocks.

The original concept was for the Spent Nuclear Fuel (SNF) to be recycled. This closed fuel cycle, the cycle in which some amount of the SNF is recycled, was touted as the hope for the future of electric generation in the nation. The US pursued an aggressive campaign of supporting the closed fuel cycle because of all the "paper advantages" of the system. It seemed only rational, since the SNF could be efficiently used as much as three more times in the existing commercial Light Water Reactor (LWR) cycle, that the fuel should be reprocessed. More so, it would have presumably been used in some form of fast reactor, a type of reactor that has no moderation and can efficiently use a wider range of fissionable isotopes, which would once again allow it to be used in the LWR fuel cycle.

However, this dream never materialized because of both the cessation of the commercial fast breeder reactor program and declining interest in commercial reprocessing. The main factors that contributed to this turn of events were economic viability under the existing regulatory conditions, political pressures, and social distrust of the technology. These factors are the same that must be understood today to grasp the future of the nuclear fuel cycle in the US. The following analysis will explain the nature of the obligation of the US to "deal with" SNF. The balance of the paper will be spent discussing several key points related to the socioeconomic conditions concerning reprocessing and SNF disposal in the US. This will not be an exhaustive analysis, but will try to touch on the most important factors of economics, politics and policy that will influence any decision to reprocess in the US. As a final note, the paper will discuss some of the basic factors that make Yucca Mountain in particular an interesting site for a possible reprocessing facility.

1.2 The End of the Nuclear Fuel Cycle and the Legacy of the Nuclear Fuel Process

It was determined by the late 70's that long-term isolation of HLW from the biosphere was the most appropriate solution for its disposal. Furthermore, the Ford and Carter administrations had decided that, due to concerns about the proliferation of weapons usable

material, commercial reprocessing would not be pursued in the United States. Until this point, it was assumed that reprocessing would play a major role in the nuclear fuel cycle. However, the only operational commercial reprocessing venture, the Nuclear Fuel Systems plant at West Valley, permanently closed in 1975. This plant shut down due to regulatory pressures and lack of a successful business model that could compete with the cheap and declining uranium prices of the day. However, the final decision by Carter in 1977 ensured that the growing stockpiles of SNF had to be dealt with in some way other than reprocessing.

The debate over disposition was mostly academic for many years and focused on the possibilities of sub-seabed, salt mine, and deep mine disposal. But, by the early 80's it had become a national imperative to find a specific site. Thus, the Congress passed the Nuclear Waste Policy Act (NWPA) of 1982. This bill obligated the DOE to compare alternatives and decide on the most appropriate solution to the dilemma as well as to begin physically taking possession of all commercial SNF by 1998. However, promptly after the NWPA 1982 had been signed, the states in which the various recommended sites were located began to fight vigorously to *not* have their state's site chosen. The final result of this bill was the elimination of all but the most likely site, Yucca Mountain, in Nye County, Nevada. Although further research into the site was vital, Yucca seemed to be the best candidate both technically and politically because of the nature of Yucca itself as well as the relatively high federal influence in Nevada.

Currently, nuclear waste is stored in 131 sites in 39 states. The total quantities can be measured in various ways, but all told there are over 40,000 MTHM (Metric Tons of Heavy Metal equivalent) and millions of gallons of high-level waste from DOD and other reprocessing ventures. The two different types of waste are in very different forms. The SNF is in the form of pellets of which, by weight, about 95 % are uranium, 1% is transuranic material (TRU, isotopes with a higher atomic number than uranium) and the remaining 4% are fission products. These pellets are in fuel rods that are either stored in cooling pools or in dry casks above ground at nuclear plant sites and elsewhere. The liquid High-Level Waste (HLW) is stored in underground vats. The permanent waste form of the liquid HLW will be as borosilicate glass, zeolite or a calcine grain material because of its low solubility and chemical stability.

1.3 The NWPA in Detail

The Nuclear Waste Policy Act of 1982 (NWPA 1982) itself passed originally only "to issue general guidelines for the recommendation of repository sites."¹ The United States Government (USG) had already taken responsibility for "byproduct material" of the nuclear fuel cycle in the Atomic Energy Act of 1954.² The ultimate

solution was thus to be determined by what was then the Atomic Energy Commission (AEC). The NWPA of 1982 provided the DOE, which was the successor of the AEC, with a competitive process to develop criteria by which to judge possible repository sites. This process pushed for several sites to be superficially analyzed and a select few to go through deep scientific scrutiny. Of these sites, the statutory requirement was for the President to choose one and recommend it to the Congress. Other important provisions were:

1. A second site must be recommended by the time the first site has received 70,000 MTHM loading.
2. To provide for the creation of a Monitored Retrievable Storage (MRS) site if necessary
3. The Nuclear Waste Fund (NWF) was established at 0.1 cents per kWh produced by nuclear power plants.
4. "The Secretary shall continue and accelerate a program of research, development, and investigation of alternative means and technologies for permanent disposal of high-level radioactive waste..." Section 222

As the investigation went forth, it became apparent that the political issues with the siting of a repository had become too caustic to have a regular process of debate and technological development. The Congress realized that any site recommendation would only lead to greater controversy and not progress on the issue. Finally, after much debate, the Congress amended the NWPA 1982 with the Nuclear Waste Policy Amendment Act (NWPAA) 1987.⁴ This ended all debate concerning the site selection process and, by statutory decree, chose Yucca Mountain as the only site to be explored for permanent geologic isolation. However, Section 222 was left unchanged and remains as stated.

This small section is the legal basis for the following discussion. It is indeed the statutory obligation of the Secretary to pursue alternatives. The current plan for Yucca Mountain designates it as a Monitored Geologic Repository (MGR). In other words, it will be loaded but not back filled and closed until it is found to be the best alternative. This was not specifically stated in the NWPA as a requirement, but it implies the response of the Secretary to Section 222, that at some point it may become feasible to reprocess and thus the option should remain open. To meet this goal, Secretary Abraham has just recently designated the Idaho National Engineering and Environmental Laboratory as the new center for the Generation IV initiative as well as Advanced Fuel Cycle research. The three main areas of interest for a discussion of reprocessing in the US are economic, political and policy.

Chapter 2: Economic Analysis

2.1 Laying Out the Debate and a Brief Economic History

The two economic factors by which components of the nuclear fuel cycle will be evaluated are: the direct profitability of the component, and the ability of that piece to optimize the entire cycle. France, Japan and the UK have all chosen to pursue the closed fuel cycle. However, none of them publicly quote net profits from their mixed oxide (MOX) fuel processing and fabrication alone. The nature of their choice of fuel cycles is based on a national desire for fuel supply security or more convincingly, fuel cycle economics, rather than on fuel sale economics

Japan has no natural reserves of uranium. This has motivated this small island country to actively pursue reprocessing and plutonium recycle. France and Britain have established long-term disposal contracts and argue that the reduction of waste volume significantly optimizes their fuel cycles. The US, unlike Japan, has large domestic supplies and very strong relationships with the major uranium suppliers of the world. However, similar to the European fuel cycles that decided to reprocess, the US estimated that in 1975, reprocessing would have had a 14% economic advantage over the once through fuel cycle but nonetheless, pursued the open fuel cycle.¹⁹

This discontinuity in the decision making process has to do with a number of historical factors as well as political realities. Currently however, stronger than any other single argument, the front end, back end and plant side changes in economics have made it infeasible to pursue nuclear reprocessing. Historically, during the heyday of nuclear energy, there was a widespread belief that a shortage of uranium was near. This exaggerated predictions of future uranium prices and was able to tilt the scales enough to result in a calculated 14% benefit. Uranium prices were sometimes higher than \$40/lb U₃O₈^a – over 4 times today's price! Now however, assuming similar conditions to those that exist today, a similar analysis done by Energy Resources International shows that if plutonium recycle were implemented in the US in a manner similar to the European model, it would cause a 38% *increase* in the fuel cycle costs.^{19,20} (See Appendix A)

The final result of an analysis based on today's conditions suggests that it is economically infeasible to reprocess in the United States at this time. Still, note that the Yucca Mountain facility is being designed to operate as an MGR site for *up to 300 years*. Moreover, the Yucca Mountain facility has become dauntingly expensive at nearly 60 billion dollars, according to 2001 estimates.¹³ The following sections are devoted to outlining some of

a. This is based on Year of Estimate 2000 dollars

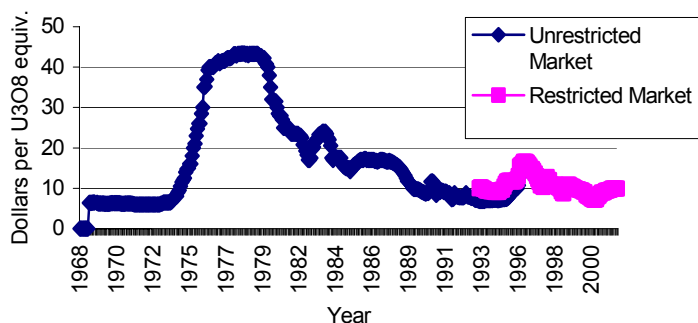
the basic economic factors of the front and back ends of the fuel cycle that will affect a reprocessing venture in the US.

2.2 Significant Front End Fuel Cycle Characteristics

The front end of the fuel cycle is usually separated into mining, milling, enrichment, and fabrication operations. The MOX option supplants these steps with reprocessing and fabrication. Although the investment necessary for a MOX fabrication plant and the barriers to entry for MOX from uranium enrichment plants will play a significant role in the eventual timing of any deployment, these front end factors are expected to be much less volatile in the long term than the effect of uranium prices. There are two factors that directly depress the price of uranium in the US in both the short and the long term. Most recently, The US-Russia Highly Enriched Uranium (HEU) agreement¹⁸ has stabilized the uranium market at its current level and will in the coming decades, keep the prices as they are. However, the market itself has been on the decline for decades and seems to have hit a stable plateau before the HEU agreement. The primary factor controlling the market is the stability and abundant supply of foreign uranium.

The lack of demand for new nuclear power plants in the early 1980s and the discovery of rich veins of uranium coupled with the fall of the uranium cartel, a group of uranium mining companies that colluded to artificially raise the price of uranium in the mid 1970s, caused a dramatic decrease in prices from 1979–82 and a more reasonable descent until about 1993. During this time, foreign suppliers have been able to consistently undersell domestic mines and have gained nearly complete market dominance. Currently, the US supplies less than 5% of the U_3O_8 it consumes. The beginning of a price plateau is detectable in the early 1990s at the same time when many of the lower quality mines were shutting down. The bulk of the current feed comes from Australia and Canada with lesser amounts coming from Africa and Russia. This plateau evened out in the following decade and has since been bouncing back and forth around \$10 per lb. This is shown in Figure 1.

Figure 1^{25,26} – The Price history of U_3O_8

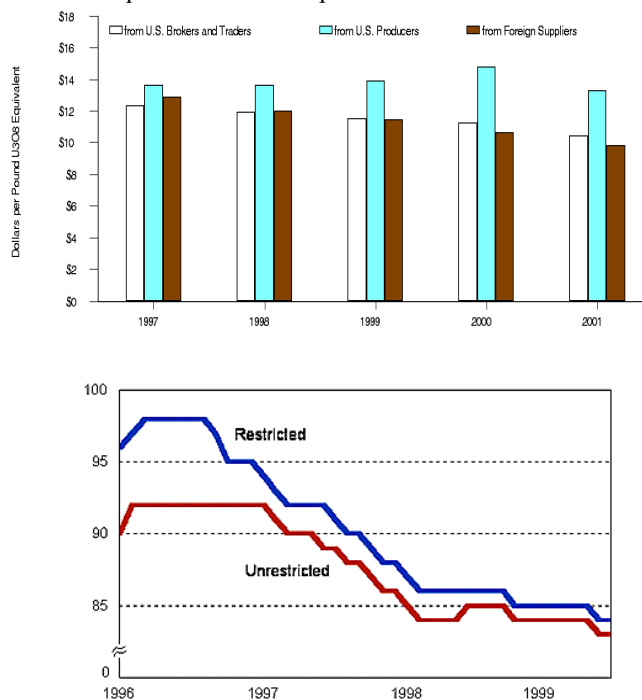


The Nuclear Energy Agency's Red Book¹⁰ claims uranium market prices should not experience much upward pressure in the next decade. At this point however, according to most estimates, the bulk of Reasonably Assured Resources (RAR) at the going market price will be exhausted and prices will begin to rise. *This price increase will provide the primary signal for a rejuvenation of interest in MOX fuel.*

However, the current United States Enrichment Program, Megatons to Megawatts, which down blends weapons grade uranium into reactor fuel, supplies up to 20% of US requirements for uranium. Furthermore, the US gained nearly 50% of its SWUs, (a SWU, Separative Work Unit, is the basic unit used to measure the energy used to enrich uranium) from the down blending of HEU in 2001.⁸ Until all 500 t of HEU and the 68 tons of plutonium to be disposed of under the US-Russia plutonium agreement⁹ are exhausted, the short-term viability of reprocessing is gone as a result of the price depression caused by this cheap source of SWUs and U.

To illustrate, in 1996 the prices were rising, but the acceleration of the HEU agreement's timetable caused prices again to fall. Ever since the agreement, prices for uranium and enrichment services have steadily decreased as shown below in Figure 2.

Figure 6,⁷ 2 – Price History of U_3O_8 Equivalent and SWU in dollars per lb and dollars per SWU



In summary, it might be as long as 20 to 30 years before the majority of the influence of HEU and plutonium stockpiles have left the market and reprocessing can again be considered as a viable supplement for the current front end. At this point, the

uranium market may have changed enough to warrant a serious look into MOX fuel as an economic resource. However, reprocessing was being considered as having a net benefit only when uranium prices were 4 times what they are today and on the increase. According to Julian Steyn of Energy Resources International, uranium prices will need to be similar to the prices in the 70's to economically justify any investment in reprocessing by the industry. This will most likely not occur in the next several decades either.¹⁹

In summary, to justify an investment in reprocessing according to the front end, there must be an acceptable price of uranium. It is currently the USG's trend to avoid participating directly in the nuclear fuel cycle. This is best seen in the example of USEC where the US has recently privatized its interests in the enrichment market. Thus, if any investment comes, it is likely to come from the private sector. Foreign investors are more likely than domestic to invest in a reprocessing facility because the experience and investment of BNFL and COGEMA would make a US company reluctant to try to compete. It should be noted that the type of fuel produced by the different forms of reprocessing could drastically affect the scenario in which it will be used; however, this will not be discussed in this paper.

2.3 Back End Conditions for Reprocessing Viability

Reprocessing, like any form of recycling, is just an alternative to permanent disposal of the end product of the cycle. The back end of the nuclear fuel cycle has focused solely on permanent storage for the past 20 years. The basic issues that must be addressed for the back end to change are two-fold. First, could the reprocessing of SNF prove to positively affect the viability of the Yucca project? Second, could *the Government* realize a high level of avoided costs by storing HLW in place of SNF at Yucca Mountain? In other words, if the USG could show that, across the entire scope of its fuel cycle activities, there was a net reduction in total expenditures due to reprocessing, there would be an economic incentive for the government to support a reprocessing venture.

Pertaining exclusively to the back end, under current designs, there will most likely not be a large net increase in storage capacity due to reprocessing. This is because of the nature of the repository. The limit on repository capacity is currently not based on volume but rather on thermal loading. In other words, although the reduction of the volume of waste to 20% of its original will reduce the cost of emplacement and packaging, it will not significantly increase the total amount of spent fuel that can ultimately be dispositioned. Almost all of the heat produced in nuclear waste comes not from the material that would be separated out for reuse by reprocessing, but rather from the shorter lived and highly active fission products.

However, the effect on the viability of the facility lies yet to be determined. The idea of anything man made lasting 10,000 years without disruption of some sort is hard to imagine. The storage of HLW instead of SNF would change the nature of the project. The resulting waste, although it might contain significant levels of uranium and other TRU materials, would effectively be environmentally benign within 1000 years. This is a much more palatable length of time especially for analyzing potential geological events that could affect the repository.

Another effect of reducing the critical storage time would be, rather than increasing the quantity of waste to be stored, reduction of the cost of storage. For example, the latest Yucca designs include titanium drip shields that are expected to extend the time in which the waste could be isolated from all contact with water. The Independent Cost Evaluation cited these particular components as introducing great price uncertainty for little real benefit.¹⁵ More important, these shields could increase the cost of the facility by as much as 7 billion dollars. Thus, there are two possibilities that occur in the case where waste is reprocessed. First, the volume of the waste is reduced and thus the drip shields become smaller, introducing a cost savings. More rationally, in the scenario considered above where critical storage time is reduced to the more manageable 1000 years, there is no need for the shields. The shields are in place to extend the isolation of the SNF up to and beyond the license period of 10,000 years. However, the need for drip shields is based on dose calculations that find the maximum dose rates to appear after the fission products have decayed away.⁶ This dose comes from uranium and plutonium that would enter into the water table. However, removing the plutonium and uranium from the calculations makes the titanium drip shields irrelevant. Other advantages and disadvantages might show themselves under careful scrutiny; however, this example demonstrates the significant cost savings that could be introduced from storage of HLW in place of SNF.

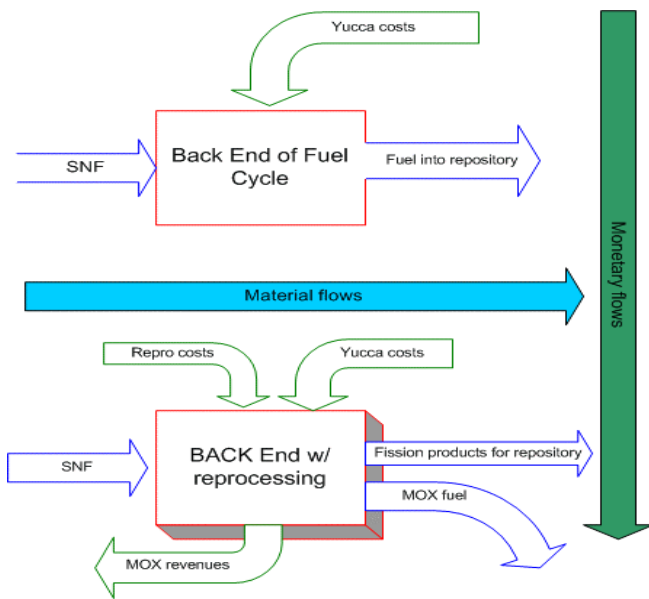
2.5 Net fuel Cycle Efficiency

What are the fuel cycle economics that make the use of reprocessing feasible in Europe? Currently, nearly 20 reactors in Europe use about a 1/3 core of MOX fuel. This is a small portion of global fuel consumption as compared to the more than 400 reactors worldwide. Also, according to the testimony of representatives of BNFL and COGEMA, at the going rate, there is no economic advantage to entering into long-term contracts for SNF reprocessing. In the experience of La Hague and Sellafield, Europe's two large reprocessing facilities, the basic factor allowing them to compete is the existence of long-term fuel storage contracts and existing capital investment. Thus, the justification of the technology *is not* a direct profit from the sales of the MOX but rather *was* a net optimization of the national fuel cycle. It is doubtful,

that under current market conditions the US will feel significant pressure, like Japan has, to seek its SWU from reprocessing, owing to its close relationship to the U rich countries of Canada and Australia and the projected continuation of flow of Russian HEU. Second, the price of long-term storage contracts has already been paid for by the utilities in the form of the Nuclear Waste Fund.

The answer to the more global question of what the conditions would need to be for global fuel cycle to improve due to reprocessing, may lie in a report soon to be released to Congress by the DOE. Overall, however, the ultimate threshold for MOX is defined by that point where the use of a MOX fuel cycle becomes directly competitive with a U fuel once through cycle. In other words, as depicted in Figure 3, if the revenues from MOX fuel, plus the avoided costs in long-term disposal, minus the cost of making the fuel, can compete with the uranium-only once through cycle, it will become a fully competitive addition to the back end of the fuel cycle.

Figure 3 – The Back End of the Nuclear Fuel Cycle With(top) and Without(bottom) Reprocessing. Avoided costs are defined as the cost of Yucca without reprocessing minus the cost of Yucca with reprocessing..



A second more important argument arises in the idea that the design of Yucca must be final and have some level of benchmarked experience with which to justify this factor.

However, the possibility that real savings would occur in the waste volume reduction implies that the proposed reprocessing facility is in fact doing a service for the USG. If these savings are not immaterial, it is important that the proposed facility receive some compensation. In other words, since reprocessing in essence would be a part of waste management, *payment from the Nuclear Waste Fund should be made to the reprocessing facility based on the savings as compared to*

the no-recycle case. This would provide funding to either amortize the plant or offset the cost of MOX to make it more competitive.

The result is that, according to purely front-end economics it will be many years before a plant will be deployed. However, in the scenario of steady growth of the nuclear generation industry, a reduction in back end costs coupled with a policy of paying for the service of reprocessing based on net savings, could make the plant feasible before the uranium market would otherwise justify it. The issue is examined in a 1985 Office of Technology Assessment report. “*Managing the Nation’s Commercial High-Level Radioactive Waste*”¹⁶ wherein it is stated,

“Available analysis strongly supports the conclusion that reprocessing is best viewed as a possible measure for extending energy resources rather than as a waste management step.”

William Magwood, director of the Office of Nuclear Energy, Science and Technology at DOE, has further confirmed that no matter the future scenario, under current conditions, it will be more expensive and thus less efficient to use reprocessing as a part of the waste management strategy. However, as the time approaches for final designs of the Yucca facility to be prepared, the total cost estimate could reach a level in which this would change. This analysis will be a key component of the INEEL mission relating to advanced fuel cycles and requires expert attention.

Chapter 3: Political Analysis

3.1 The Crowd that Said Nay

The idea of coupling a reprocessing plant with Yucca Mountain, though not equivalent to the decision for the repository itself, bears much similarity in the type of reaction that it should expect to receive. Thus, to illustrate the basic factors that will most likely play a key role in the decision, the following section will explore the Yucca Mountain repository decision itself. There are perhaps four main camps in the debate over the Yucca Mountain project. The strong opinions of these organizations have effectively rallied behind them a large number of previously uncommitted parties. Each one subscribes to either being for the project or against it for various reasons, most of which however relate to nuclear energy itself rather than Yucca Mountain. The camps, though not set in stone, are fairly similar to what most major industrial projects encounter Nevada NIMBYs, antis, other states’ NIMBYs and pro-nukes.

The first group and the most staunchly resistant were the Nevada NIMBYs. NIMBY, or *Not In My BackYard*, has become the catchall phrase for the local protest groups that pop up around nearly all industrial

projects. This does not imply that they are not justified in their opinion, but the sentiment has become somewhat of a burlesque in the press. Everyone wants a new power plant online but not anywhere near *them*. It is a common dilemma and indeed it was one of the most relevant factors that went into the site decision at Yucca Mountain. The site is in one of the most desolate areas in the US and has no population center near it for many miles in any direction. It is on federal land just outside the Nevada Test Site where, throughout the Cold War, hundreds of underground and above ground nuclear tests were performed. The land is no one's "backyard."

However, many people of Nevada do not agree. Learning from the experience of the environmental disaster that is the Hanford DOD hazardous waste site, the people of Nevada have been enraged concerning the use of their state as the site of this nuclear waste "dump". There is no doubt that, as can be shown by the history of the Hanford site, nuclear cleanup is both essential as well as complicated. If the people of Nevada feel that they are receiving a site like Hanford, they ought to be enraged. The site itself will bear little resemblance to Hanford, and pose, by any reasonable consideration, a much lower and more manageable risk.

Still, armed with teams of anti-nuclear groups to back them up with petitions and vigorous anti-nuclear lobbyists, they have successfully put the project years off schedule and were able to bring the entire project to a dangerous state of stagnancy in the Senate. The main NIMBY activists have been basically the media sources and the politicians of the state of Nevada. Their lobbying campaign focused on three main points.

- 1) *The facility is unsafe.* This has not held water with any of the organizations and firms that have been asked to analyze the facility. However, through effective misrepresentation the public has grown to doubt the facilities scientific bases.
- 2) *There has to be a better solution.* To hold off and find another way of permanently storing or else wise "dealing with" the waste has been the focus of much debate. Shelley Berkley (D – NV) has proposed a bill in the House to support aggressive funding of advanced fuel cycle technology and Sen. Ensign (R-NV) is on record during the July 9th Yucca debate as supporting

transmutation and reprocessing as "solutions" to Yucca Mountain.^a

- 3) *The transportation of the waste is unsafe.* The details of this point are not necessarily relevant. However, the cost of this transportation to ensure security to a reasonable level proves that, on some level, the DOE agrees and is taking extreme measures to secure the waste during transport.

The most important players on this side have been the editor of the Las Vegas Sun editor, Brian Greenspun, Nevada Governor Guinn, Nevada Senators Reid (D-NV) and Ensign (R-NV) and all the other Members of Congress from Nevada and neighboring southern California. Guinn and Members of Congress from Nevada had their role more or less defined by the sentiments expressed by Greenspun. His biting and emotive criticisms of Yucca Mountain have influenced nearly all the newspapers in the State. His reviews, though rarely technically sound, have made it politically unsavvy to be pro-Yucca Mountain in Nevada and indeed have made this barren mountain the backyard of all of Nevada. For this reason, Senator Reid has been the most active opponent of the Project.

Reid is a very powerful member of the 107th Congress. He is the majority Whip as well as being the Chairman of the Senate subcommittee on Water and Energy Appropriations. He has made the issue of the utmost personal importance and has influenced Senators on both sides of the aisle either by his personal friendships^b, or through the overt power of his Chairmanship. Similarly Gov. Guinn has taken numerous steps and done everything in his power to delay the project. Recently, the Governor vetoed the DOE's decision to proceed with the presentation of a licensing

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- a. This is not in any way true because in either case the repository would serve the same purpose, to hold radioactive waste, whether it was or was not reprocessed. Neither would transmutation be capable of truly destroying the radioactivity of the fission products, the hottest and most dangerous component of the SNF.
 - b. Senator Carper of the Committee on Energy and Natural Resources, stated at the final committee markup as well as the July 9th debate that, although he was very pro nuclear and pro Yucca Mountain, because of his personal friendship with Sen. Reid, he would vote against the S.J. Res 34 unless his vote was utterly necessary to approve the motion.

permit to the NRC for the site. He was granted this right under the NWPAA 1987 and, as the procedure requires, this was sent back to the Congress. The resolution to override the Governor's veto passed the house by a margin of 306 to 117 and the senate by 60 to 39.

However, in both cases the bulk of the votes against did not come from Nevada and the NIMBYs. The true core of the resistance to the Yucca Mountain project comes from the anti nuclear organizations. Sometimes named BANANAs (*Build Absolutely Nothing Anywhere Near Anybody*) or NOPEs (Not on Planet Earth), the coalition against Yucca refers widely to the national groups that would most currently be classified as Greens. The Greens, although a fringe group and hailing to only a very small number of registered voters, have gained the ear of the liberal press. They have also been able to rally such respected groups as the Sierra Club to endorse the anti-Yucca campaign.

The vigorous campaigns of noted anti-nuclear activists such as NCI (Nuclear Control Institute) and Ralph Nader's group Public Citizen, have proven to be very effective in raising the public's fear over issues relating to SNF. Although their "facts" have proven to be quite fluid and prone towards the inflammatory, their objective has been solid from the beginning. The current alliance has rallied behind the anti-Yucca effort to effectively "choke the nuclear power industry with its own waste" in the words of Nightline commentator Ted Koppel.¹² This is indeed one of the basic tenets of some of the foremost members of the coalition, namely Greenpeace, Sierra Club Public Citizen et al.

This is not to imply any particular weakness in some of their points due to ulterior motives. Some writers, such as Arjun Makhijani from the Institute for Environmental and Energy Research, a firmly anti nuclear organization, argued eloquently and reasonably for a return to the 1982 NWPA,¹⁷ noting concerns over the validity of the site recommendation. The arguments though noted, were not convincing nor particularly deep as they dismissed the political process that had led to the NWPAA 1987. Most of the focus of these groups was on the development and interpretation of data that could effectively win over the more liberal Democrats and cause the American public to be more afraid of the nuclear industry in general. Although many meetings and discussions were sought with key members of the anti-nuclear movement, they were highly unresponsive to the researcher. Thus, the bulk of their argument had to be gleaned from public documents.

3.2 The Crowd that said Yea

The contra-NIMBYs are simply stated, the contingent of US states that have waste within their borders and want it out. This group made up the bulk of the votes for Yucca Mountain but did not necessarily with their vote imply any higher level of support for nuclear energy. Any support for nuclear energy exemplified in this decision had to do with the pressure felt in the contra-NIMBY states was due to their reliance on nuclear power.

However, the catalysts for the entire process were the pro-nuclear Congressmen. More than any other, Sen. Murkowski(R-AI) has fought for Yucca to go forward. With the support of other key Senators on the Energy and Natural Resources Committee, this 20-year process was finally brought to a head during the Bush administration. The ultimate concern of these few advocates, is the rebirth of nuclear energy and an increase in America's energy security as well as environmental record. Supported by DOE, the Nuclear Energy Institute, American Nuclear Society, and a host of other technical, labor, and industry groups, they fought against the BANANAs and Nevada NIMBYs to provide pressure on legislature and executive officials to allow the Yucca plan go forward.

3.3 Theoretical Response to a Reprocessing Plant

To come full circle and draw a comparison of all these groups to the reprocessing debate, consider each one and its relationship to nuclear power. First, all groups except the BANANAs respond on some level to economic factors. They will undoubtedly oppose any such project because of its perceived benefit to the nuclear industry.

In principle, Nevada will support the project. In fact Sen. Reid has just recently acquired \$4.5 million for transmutation related activities at UNLV. This is because any investment in improving the safety and viability of the project would in fact make it more desirable to Nevada. However, there are two scenarios, either the plant is in Nevada or elsewhere. The Nevada NIMBYs would most likely resist any possible implementation project in their state until a major shift in philosophy occurs. This is a possibility to be discussed in section 5.4 Still, as has been seen both in recent reporting, as well as the Nye county representatives, there is a very real possibility that Nevada will change its philosophy and eventually start to demand large infrastructure projects, including a major research facility at Yucca Mountain, in the near future. If this trend continues, it is very likely that there would be a major incentive for the Nevada-NIMBYs to change their opinion and seek a reprocessing plant at home. However, this is pure conjecture. The second scenario, where a plant is built in another state and waste is routed to and treated there, this is in fact something that Senators Reid and Ensign along with a significant portion of Nevada Members would most likely support heartily. This is influenced by the possibility of both stalling the Yucca

project as well as displacing a significant quantity of the waste.

The contra-NIMBY camp will have shifted dramatically by the time any proposed reprocessing plant comes on line. All the same states will not have nuclear plants in operation or more importantly, most leadership will have changed by that time. Those states without operating plants will most likely oppose any reprocessing facility as well as any perceived assistance to the nuclear fuel cycle. However, those states that continue to have nuclear plants would be more prone to support any plant.

Finally, because any plant will be many years away, leadership will have changed too dramatically to make any conjecture concerning plant deployment. The only firm observation would be that, in light of the latest decision by the DOE to designate INEEL in Idaho as the center for advanced fuel cycle studies, it is likely that Members from Idaho will more than likely provide some level of leadership when the time comes.

Chapter 4: Policy Analysis

4.1 Policy History and Brief Analysis

In 1977 Jimmy Carter made an executive order to indefinitely stop all reprocessing of SNF in the US. This effectively terminated the US's commercial reprocessing industry. Although this order was later rescinded by President Reagan, there has not been any further interest in commercial reprocessing in this country. Companies that had the relevant technical capability were unwilling to pursue the matter in view of the huge capital investments that would be required and the unstable political nature of reprocessing; it was considered to be unlikely that there would be profit in the venture. Carter's decision based on non-proliferation concerns, although to some nuclear activists, was a misrepresentation of facts, was substantiated by a secret Ford administration study concerning the nuclear fuel cycle's proliferation resistance. Since that decision the issue has more or less remained dormant, receiving only enough funding from the DOE to keep important staff on board and occupied, while basically being ignored as a matter of public importance.

However, Vice President Cheney's Energy Policy proposal made specific reference to the importance of accelerated exploration into advanced reprocessing and transmutation concepts. This tremendous shift in national policy away from the Ford/Carter administration's legacy represents a fundamental difference in the perception and understanding of nuclear proliferation. The necessity to remain on the forefront of reprocessing technology gives the US the ability to act globally in accordance with its non-proliferation goals through positive engagement rather than solely restrictive and adversarial measures. This has been one of the driving forces behind the

retention of reprocessing research in the US since the failure of the commercial reprocessing industry. For the time being this justifies its continuation.

Finally, the existing NRC policies are not prepared to deal with emerging technologies. After the Carter years, the books were closed. Although DOE continues to have some reprocessing of naval reactor fuel, the plants are of the PUREX type. The only new regulatory activity concerning reprocessing in the previous decade related to the manner in which to decommission West Valley. This is a major stumbling block to any future advances in the realm of reprocessing. Any modern plant would not resemble the West Valley generation of plants any more than the Generation IV nuclear plants resemble the Generation II. A complete review of the regulations governing commercial reprocessing much like the recent review of Generation IV licensing procedures, would be necessary before any proposed plant could move forward. However this is not warranted until the following conditions are met:

1. The DOE receives significant funding for research into commercial use of reprocessing
2. Uranium prices or other fuel cycle conditions change enough to justify some level of interest from the commercial industry.

Chapter 5: Observations and Conclusions

5.1. Economic Observations and Recommendations

It is extremely unlikely, due to the factors enumerated in the previous sections, that any commercially viable reprocessing and MOX fabrication facility will be considered in the next 20 years. The price of uranium is simply too low to justify any investment. However, considering that the nature of the use of a closed fuel cycle affects the global fuel efficiency, reprocessing cannot only be analyzed with respect to the competitiveness of MOX.

Thus, it is proposed that a major investigation into the difference per MTHM for the ultimate storage cost of HLW in place of SNF be performed as soon as the NRC has certified a final design for Yucca Mountain. Although the Office of Technology Assessment determined, in 1985, that reprocessing¹⁶ would *not* result in a net benefit in waste storage at a permanent repository site, the situation and design of the facility has changed too dramatically to rule out the change in average cost per MTHM disposed.

These savings must be added onto the net *profits* for any theoretical balance sheets of a reprocessing facility. This balance transfer per MTHM treated, if it is substantial enough, could lower the net cost of MOX fuel such that it could compete with U fuel before the market might otherwise have determined and provide a net savings for the government's operations at Yucca.

It must be noted that this line of argument implies that a final storage design has been decided upon for Yucca Mountain. This storage design, although the DOE claims a date as soon as 2003, would more likely appear later and take longer to build than predicted due to the ensuing legal and appropriation battles. This gives the government the time to undertake said studies as well as to conclude the Nuclear Energy 2010 initiative, the decisive factor in the rebirth of the nuclear industry.

The emplacement of a pilot reprocessing plant as well as the study of the total fuel cycle costs, could, in the long run, stave off a complete brain drain of technical expertise in the US and, in the same way, provide the US with a valuable asset of capital and experience. Still, it does not commit the US to reprocessing. Thus, it would be reasonable at this point to study the viability of building and operating an advanced fuel cycle pilot plant at INEEL.

5.2 Political Observations

The political barriers for any reprocessing facility are immense. However, assuming new nuclear plants are built, these barriers are not insurmountable. Technical problems, though not insignificant, are a known quantity and *in the low technological growth case*, the next 20 years will show no dramatic improvement in reprocessing and a wet chemical process will continue to be used in a modified form such as Uranium Recycle by Extraction (UREX) process. Finally, social barriers will persist until nuclear energy as a whole can change its image to a more socially acceptable form of energy generation.

The statements by Sen. Ensign of Nevada and Rep. Berkley from Las Vegas, do not in any way endorse nuclear reprocessing. Indeed these statements were just political tactics to stall the Yucca Mountain vote. The most important single backing for the rejuvenation of reprocessing is in the US Energy Policy bill currently in Committee. There will undoubtedly be major shifts of perspective and in this new environment of energy and environmental concerns, it seems more likely that some rising politicians as well as social organizations will grow to support nuclear energy.

5.3 Policy Observations and Recommendations

The subtlety of the three themes discussed in this paper, modern policy concerning reprocessing technology, is enigmatic at best. The NRC has no intention of exploring the matter at this time. Indeed, it is completely occupied with other matters relating to nuclear security, plant relicensing and plant siting. At this time, it is not necessary to pursue any regulatory policy in the US

If and when DOE receives significant funding for advanced fuel cycle research *and* uranium prices being to climb due to resource shortages, it is recommended that the NRC make firm plans to revisit the issue of reprocessing.

As a final note, the international examples of La Hague and Sellafield show that plants can be operated safely. However, a restrictive regulatory environment necessarily precludes any facility being built. Thus, it is recommended that, many of the out of date and over protective regulatory statutes relating to Environmental Protection Agency (EPA) mandated dose limits be rewritten to better reflect the best possible science relating to the operation of nuclear facilities and specifically, the Yucca Mountain repository as well as any proposed reprocessing facility. NRC Chairman Meserve has drawn specific attention to water and air dose rates that have proven to be overly stringent.

5.4 Final Observations and Future Work

This paper has dealt with general factors that would need to exist for there to be a reprocessing facility in the US. The choice of Yucca Mountain as the focal point of the argument was initially due to the relevance of the current debate to the issue. However, if the current transportation scheme can be said to be representative of future transportation of nuclear waste, the centralization of the US SNF at the site decisively recommends it for further investigation. The benefits are similar to those seen in the modern coal industry. Many coal plants are located directly at the mouth of a mine. The idea of a reprocessing facility at Yucca is based on similar logic. The Yucca site could eventually be, in a manner of thinking, a large plutonium and uranium mine.

The primary relationship between Yucca and reprocessing is that the site currently represents the culmination of the open fuel cycle. However, once it has received a great deal of SNF, it will become a very interesting place for a reprocessing plant in the event of the rejuvenation of the closed fuel cycle. The Yucca mountain site, having been effectively chosen as the first site in the US where nuclear waste will be geologically stored, has various features that must be understood. These characteristics will be categorized as natural and designed. Firstly, the same natural features that justify the repository site, benefit the possible reprocessing site. These are as follows,

- 1) *Yucca Mountain is desolate and isolated.* Yucca Mountain is 90 miles north of the closest population center, Las Vegas and in close proximity to the main US nuclear bomb test site; Yucca is in a very sparsely inhabited region in Nevada that is highly protected by natural as well as national defense related barriers. Thus, physical

protection and environmental mitigation of risk is an intrinsic feature of the site.

- 2) *Yucca Mountain has available water supplies.* According to testimony by Nye County representatives, there is a plentiful aquifer nearby that could be diverted and used in or nearby the Yucca site. This provides the possibility of building a major industrial complex on site.
- 3) *Yucca Mountain has been given a tentative but clean bill of health.* It is on an isolated water table and has the most highly studied geological as well as hydrological characteristics in the nation. The Nuclear Waste Technical Review Board (NWTRB), as well as the International Research Team (IRT), found no “show stoppers”, from a technical standpoint.^{4,5} In other words, it is naturally quite stable and has low natural flow of radiological and indeed any materials from its site, making it a good site for the purpose of environmental mitigation of risk.

Some engineered and human related characteristics that make Yucca an interesting site are;

- 1) *Yucca Mountain is likely to already have the infrastructure for major industrial operations.* Many millions of dollars in investment in transportation, electric grid and human services will be emplaced in the coming years at and around Yucca Mountain.
- 2) *UNLV and Nye county representatives are seeking huge investments in research labs, projects and partnerships.* The little spoken of but continually implied result of Nevada being forced to have Yucca Mountain is that it will receive billions of dollars in related projects. Nevada had a 100 million dollar budget deficit last year. The project was even recently endorsed by the Former Governor List of Nevada when he said,

“Nevada needs a financial shot in the arm. Construction dollars are going to be spent in Nevada, and there will be ongoing money spent on services and goods far into the future.”¹²

- 3) *All the SNF will already be at the site.* Opponents to the site have been vehement in the last several years that it is too dangerous to transport the waste at all. The DOE disagrees that it is unsafe but at the same time is estimating as much as 7 billion dollars simply to transport and accept the waste.¹³ Moreover, as evidenced by the recent battle in Congress over the movement

of the waste, it will be politically infeasible to move the waste again in the foreseeable future. Thus, it must be assumed that this will be a barrier to having a reprocessing facility in any location other than Yucca Mountain.

The technical points on which this analysis is based are beyond the scope of this paper. For specific factual bases for many of the assertions above, the government website, www.ymp.gov, provides a wealth of information.

However, there are major questions of capital investment, technical feasibility and policy that have only been superficially treated in this brief analysis. Specifically, the researcher must further explore the West Valley business model the regulatory framework that contributed to its failure. To justify the above assertion of the viability of the Yucca site for reprocessing, the following studies must be done:

- 1) A comparison between the most likely sites for reprocessing (Northeastern US, Savannah River site, INEEL) and Yucca
- 2) A firm assessment of the likely technologies that would be used in a future reprocessing plant along with the energy portfolio scenarios in which they would fit
- 3) The effect of natural uranium services on the viability of the capital investment required for a reprocessing facility.

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Appendix A²⁴ – Current Economic Comparison Between Recycle and No Recycle Case for the US Commercial Nuclear Fuel Cycle

Table 1			
No Recycle and Plutonium Recycle Levelized Fuel cycle Costs in a Postulated U.S. Setting			
Cost Component	Assumed prices(b)	No recycle (Mills/kWhe)	Pu Recycle (Mills/kWhe) (c)
Uranium	\$14/lbU3O8	0.9	0.7
Conversion	\$5/kgU	0.1	0.1
Enrichment	\$105/SWU	1.7	1.6
Spent Fuel Disposal	\$320/kgU	1	--
Spent fuel Storage	\$\$80/kgU	0.2	--
HLW Disposal	\$320/kgU	--	1
Reprocessing	\$950/kgU	--	2.1
MOX Fuel Fabrication	\$1,100/kgU	--	0.3
UO2 Fuel Fabrication	\$225/kgU	0.8	0.8
Totals		4.7	6.5

(a) levelized over 30 year power plant life. Assumes 42,500 MWD/MT burnup for uranium dioxide and MOX fuel.

(b) Projected prices after the year 2000, 1997 dollars/ Source for front end and storage prices: "1996 Nuclear Fuel Cycle Supply and Price Report", Energy Resources International Inc.: "the Economics of the Nuclear Fuel Cycle", Nuclear Energy Agency (NEA) of the OECD, 1994 Source for spent fuel and HLW disposal price is the current DOE charge of 1 mill/kWhe

(c) Assumes on average 15% of the fuel will be MOX and 85% will be uranium dioxide in typical Pu recycle economy. MOX loadings in individual reactors may be 30% or higher. Assumes MOX fuel fissile plutonium assay of 0.78 w/o; and annual reload of 20 MTHM per GWe