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December 10, 2010

Members of 76th Session of the Nevada Legislature
Capitol Complex
Carson City, Nevada 89701

Subject: Report of the Nevada Commission on Nuclear Projects

I am pleased to provide you with the enclosed copy of the 2010 report of the Nevada Commission on Nuclear Projects. The report was prepared in accord with the Commission's statutory responsibility to provide advice and guidance to the Governor and Legislature on matters involving nuclear waste disposal in Nevada. This is the twelfth such report compiled by the Commission since it was created in 1985.

While Nevada is currently facing serious economic and fiscal difficulties that will require sacrifices on the part of every state agency during the next biennium, this is emphatically not the time to abandon or lessen Nevada's opposition to this ill-conceived and dangerous project. Although developments at the federal level bode well for Nevada to ultimately be able to bring this dangerous and ill-conceived project to an end, the report is very clear that the Governor and Legislature must remain vigilant and be prepared to continue aggressive opposition to Yucca Mountain until its fate is ultimately determined.

If you have questions regarding the report or would like to discuss it further, please do not hesitate to contact me.

Sincerely,

Richard H. Bryan
Chairman

RHB/
Enclosure

REPORT AND RECOMMENDATIONS OF THE NEVADA COMMISSION ON NUCLEAR PROJECTS

Presented to
The Governor and Legislature
Of the State of Nevada

December 2010

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Preface

Humorist and political commentator P.J. O'Rourke once observed that "the mystery of government is not how Washington works but how to make it stop." It would be difficult to find a more apt example of this adage than the situation the U.S. Department of Energy finds itself in today with regard to the Yucca Mountain high-level radioactive waste repository program. Despite finding the Yucca project to be unworkable, taking action to formally withdraw the license application currently pending before the U.S. Nuclear Regulatory Commission, and going so far as to dismantle the organization responsible for implementing the program (DOE's now-defunct Office of Civilian Radioactive Waste Management), the Yucca Mountain project remains alive, with powerful interests aligned in an effort to prevent it from being scrapped.

In January 2010, when DOE announced that it was withdrawing the Yucca license application, Nevadans had every reason to believe that, after almost three decades of federal efforts to forge ahead with an unsafe and unsuitable repository site over the strong and consistent objections of the State of Nevada, reason had finally prevailed and the country was prepared to turn its attention towards finding workable solutions for managing spent nuclear fuel and high-level radioactive waste. The decision by the Obama Administration to establish a Blue Ribbon Commission to recommend alternatives to the failed Yucca Mountain program seemed to presage the ultimate demise of the project.

Yet, as O'Rourke observed, making a large and entrenched federal project stop is no simple matter – even one as flawed and bloated as Yucca Mountain. Even as DOE moved to dismantle the program, the NRC's licensing board ruled that DOE could not withdraw the license application once it had been submitted. States hosting facilities with waste destined for disposal in a future repository piled on and filed suit in federal court to stop DOE from terminating the project, even though there has been no determination as to the future fate of the license application or the ability of DOE to ever construct a repository at the site.

The continuing uncertainty that permeates the Yucca Mountain program is especially troubling for the State of Nevada. Having prepared for decades to successfully contest the license application before the NRC and challenge DOE's faulty science and manipulated findings regarding the site's suitability, Nevada now finds itself in a legal and procedural limbo. It will likely be well into 2011 or beyond before developments in the licensing, legal and political arenas will have been sufficiently sorted out to know whether Yucca Mountain is to go forward in licensing or is to be terminated, as DOE proposes.

One thing certain is that Nevada can ill afford to be complacent and naively assume that the Yucca program will go quietly into that dark night. The report which follows seeks to clarify

the current situation to the extent it can be made clearer and assess the implications of developments over the past two years for Nevada. The report is very clear, however, that the Governor and Legislature must remain vigilant and be prepared to continue aggressive opposition to Yucca Mountain until its fate is ultimately determined. While Nevada is currently facing serious economic and fiscal difficulties that will require sacrifices on the part of every state agency during the next biennium, this is emphatically not the time to abandon or hamstring Nevada's opposition to this ill-conceived and dangerous project.

Richard H. Bryan, Chairman
December, 2010

LIST OF ACRONYMS/ABREVIATIONS

ACR 8 – Assembly Concurrent Resolution 8 was passed by the 1987 Nevada Legislature and required the Agency for Nuclear Project to evaluate transportation requirements and impacts associated with the proposed Yucca Mountain repository project.

AEC – Atomic Energy Commission

AIP – Agreement in Principle between the U.S Department of Energy and the State of Nevada providing for state oversight of certain activities at the Nevada Test Site

AMFM Panel – Panel created by the Nuclear Waste Policy Act of 1982 to revaluate Alternative Means for Financing and Managing the federal high-level radioactive waste program

ASLB – U.S. Nuclear Regulatory Commission's Atomic Safety and Licensing Board

BRC – Blue Ribbon Commission on America's Nuclear Future

CAB – Construction Authorization Board

CPCN – Certificate of Public Convenience and Necessity

DOE – U.S. Department of Energy

EIS – Environmental Impact Statement

EPA – U.S. Environmental Protection Agency

ERDA – Energy Research and Development Agency

FEIS – Final Yucca Mountain Environmental Impact Statement

GAO – U.S. Government Accountability Office (formerly the U.S. General Accounting Office)

HLW – High-Level Radioactive Waste

LA – DOE's Yucca Mountain License Application pending before the Nuclear Regulatory Commission

LLW – Low-Level Radioactive Waste

LSN – Licensing Support Network

MLLW – Mixed hazardous and low-level radioactive waste

MPC – Multi-purpose Canister

NARUC – National Association of Regulatory Utility Commissioners

NAS – National Academy of Sciences

NEPA – National Environmental Policy Act

NNSS – Nevada National Security Site (formerly the Nevada Test Site)

NRC – U.S. Nuclear Regulatory Commission

NTP – National Transportation Plan

NTS – Nevada Test Site (renamed the Nevada National Security Site)

NWPA – Nuclear Waste Policy Act of 1982 – the original legislation that governed the federal high-level radioactive waste program from January 1983 to December 1986

NWPAA – 1987 Nuclear Waste Policy Amendments Act amended the NWPA and singled out Yucca Mountain as the only site to be studied as a potential repository site

OCRWM – Office of Civilian Radioactive Waste Management

RA EIS – Rail Alignment Environmental Impact Statement

R & D – Research and Development

SEIS – Supplemental Environmental Impact Statement

STB – Surface Transportation Board

Sec. 180(c) – The section of the Nuclear Waste Policy Act of 1982 that provides for training for local public safety and emergency response personnel

SNF – Spent Nuclear Fuel

TAD – Dual purpose Transportation and Disposal Container proposed by DOE as an integral component of the Yucca Mountain repository design

WGA – Western Governors Association

WIEB – Western Interstate Energy Board

WIPP – Waste Isolation Pilot Plant in New Mexico is DOE's repository for transuranic waste

Chapter 1 - Developments in the Yucca Mountain Project and the Federal High-Level Radioactive Waste Program

To characterize developments in the federal government's proposed Yucca Mountain nuclear waste repository program since the Commission's last report as remarkable, even historic, would be an understatement of the first order. In its 2009 report, the Commission observed that while the U.S. Department of Energy (DOE) was engaged in a "frenzied effort to fast track a license application to the U.S. Nuclear Regulatory Commission (NRC) and show progress in identifying a preferred rail spur to the Yucca Mountain site, the program is characterized by major uncertainties as a new Administration takes power in Washington and the State of Nevada prepares to mount the most extensive and far-reaching licensing intervention in the history of the NRC."

While the Commission at the time was cautiously optimistic that the State was moving closer to halting what had become a bloated and increasingly unworkable program, no one anticipated the speed at which the Yucca Mountain program would unravel. At the end of 2009, the NRC licensing proceeding was in full swing, with three licensing boards (or construction authorization boards – CABs) having been established, the process of discovery begun, and schedules for taking depositions established. Just two months later, DOE filed notice with the CABs that it was suspending all work on the Yucca Mountain license application and would be submitting a motion to withdraw the license application all together within 30 days, which it did on March 3, 2010.

As of the publication of this report, however, the fate of Yucca Mountain remains uncertain as the NRC and the federal courts struggle with the legal issues surrounding DOE's proposed withdrawal of the license application and as the country once again looks for workable alternative solutions to the eternally vexing problem of spent nuclear fuel and high-level radioactive waste. This report briefly chronicles the events that have impacted the Yucca Mountain program over the past two years and their implications for the State of Nevada and makes recommendations for moving ahead in the face of continuing uncertainty regarding the ultimate fate of the federal program.

DOE's Yucca Mountain License Application and the Decision to Terminate the Program

Events Leading Up to the Decision to Withdraw the License Application

DOE formally submitted its License Application (LA) to construct and operate a Yucca Mountain repository to the NRC in June 2008, six months after it had certified (for the second time) its Licensing Support Network (LSN) documents database. In support of its license application, DOE also issued three new final environmental documents (in addition to the Final

Yucca Mountain Environmental Impact Statement that had been issued with the site recommendation in 2001), including:

- Final Supplemental Environmental Impact Statement for a Geologic Repository for Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Yucca Mountain FSEIS)

- Final Supplemental Environmental Impact Statement for a Geologic Repository for Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada – Nevada Rail Transportation Corridor (Rail Corridor FSEIS)

- Final Environmental Impact Statement for a Rail Alignment for the Construction and Operation of a Railroad in Nevada to a Geologic Repository at Yucca Mountain, Nye County, Nevada (Rail Alignment FEIS).

The fate of Yucca Mountain remains uncertain as the NRC and the federal courts struggle with the legal issues surrounding DOE's proposed withdrawal of the license application and as the country once again looks for workable alternative solutions to the eternally vexing problem of spent nuclear fuel and high-level radioactive waste.

In addition to the State of Nevada, other entities (apart from NRC and DOE) initially admitted to participate in the licensing proceeding include Clark County, Nye County, the State of California, Inyo County (California), the Timbisha Shoshone (represented by the Joint Timbisha Shoshone Tribal Group and the Native Community Action Council), Eureka County, Lincoln County[1], White Pine County, the four counties of Esmeralda, Churchill, Mineral, and Lander (admitted as a collective), and the Nuclear Energy Institute.

In response to the initial DOE Yucca Mountain License Application, Nevada submitted 229 contentions to the NRC licensing board in December 2008. The majority of the contentions are technical in nature and address deficiencies in the LA ranging from flaws in the overall performance assessment model and calculations to specific geotechnical issues, such as the potential for renewed volcanic activity at the Yucca Mountain site, corrosion of the waste disposal packages, the implications of DOE's proposed use of drip shields to shelter waste packages from water in the tunnels, and other key site suitability issues.

In May 2009, the NRC licensing boards[2] accepted an unprecedented 222 out of the 229 originally filed contentions by the State. Nevada's 1,566 page petition containing the 229 contentions can be found at: http://www.state.nv.us/nucwaste/licensing/Contentions_NV.pdf .[3]

[1] Lincoln County sought and was admitted as an "Interested Governmental Participant" rather than as a full party to the proceeding.

[2] Due to the complexity of the Yucca Mountain licensing proceeding, NRC established three licensing boards, called Construction Authorization Boards (CABs), that would operate concurrently in adjudicating the unprecedented number of contentions or objections and allow the proceedings to be completed in the statutorily specified four year time-frame.

Upon subsequent appeal of the Boards' ruling by the NRC staff[4], the full Nuclear Regulatory Commission upheld all but two of Nevada's contentions, allowing 220 to go forward to be adjudicated. Subsequently, six (6) additional contentions were submitted by Nevada in response to new information that came to light after the initial license submittal by DOE. Four (4) of those new contentions were also admitted for adjudication by the licensing boards. A total of 296 contentions from all parties have been accepted by the NRC licensing boards to date.

The Discovery Phase for Phase One of the licensing hearings began October 1, 2009. Prior to DOE's announcement that it intended to withdraw the LA - and the licensing board's subsequent suspension of the licensing proceeding - the State of Nevada was actively engaged in intense activities associated with the discovery phase of the licensing proceeding and for the eventual expert testimony in support of the State's contentions. A joint proposal, developed by Nevada, set out the plan for the grouping of all the admitted contentions from all parties. This joint proposal was issued October 13, 2009.

The Licensing Boards accepted an unprecedented 222 out of the 229 originally filed contentions by the State. These contentions are technical in nature and address deficiencies in the LA ranging from flaws in the overall performance assessment model and calculations to specific geotechnical issues, such as the potential for renewed volcanic activity at the Yucca Mountain site, corrosion of the waste disposal packages, the implications of DOE's proposed use of drip shields to shelter waste packages from water in tunnels, and other key site suitability issues.

A formal hearing of the Construction Authorization Board (CAB) was held in Las Vegas on January 26th and 27th, 2010. This hearing addressed, among other things, eleven (11) important legal issues raised in contentions. If Nevada were to win on one or more of these key legal issues, the DOE license application would be crippled. Oral arguments were heard from all parties involved. This was the final step before the licensing judges were to issue their decision regarding these legal issues. The hearing also covered the issues raised by the NRC Licensing Support Network (LSN) Administrator's memorandum of December 17, 2009. That memorandum discussed potential problems with the LSN documents if the licensing proceedings were to be suspended for any significant length of time.

Prior to the suspension of the proceeding, the "Discovery" phase of the licensing proceeding had begun, and depositions of key experts and witnesses were slated to begin on February 16, 2010. Depositions would likely have continued into 2011.

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[3] The Agency maintains a comprehensive web page containing all pertinent licensing materials, petitions, orders, etc. This web page can be found at: http://www.state.nv.us/nucwaste/licensing.htm .

[4] DOE originally challenged all of Nevada's contentions, while the NRC staff recommended that only 19 of the 229 State contentions should be admitted for adjudication in the licensing hearing.

DOE's Decision to Withdraw the Yucca Mountain License Application

On February 1, 2010, the Department of Energy filed a notice with the Construction Authorization Board that DOE was suspending all activity relative to the licensing process and informed the Board that DOE would be formally petitioning to withdraw the License Application within 30 days. On February 16th, the Board granted DOE's motion to stay the proceedings and the deposition schedule. On March 3, 2010, the Department of Energy formally filed the motion with the Construction Authorization Board to withdraw the License Application for the Yucca Mountain site with prejudice. Under NRC regulations governing the licensing proceeding, the licensing board must approve an applicant's request to withdraw a license application once the proceeding has been initiated. DOE's motion to withdraw the Yucca Mountain LA included the request that the withdrawal be "with prejudice," meaning that the application could not just be resubmitted at a future time. In making the "with prejudice" request, DOE stated unequivocally that it has no intention of ever developing Yucca Mountain as a repository.

Upon learning of DOE's plan to withdraw the Licensing Application, five new entities petitioned the CAB to intervene in the licensing proceedings in order to contest DOE's motion to withdraw the application. Those entities are: the State of South Carolina; Aiken County, South Carolina; the State of Washington; the Prairie Island Indian Community; and the National Association of Regulatory Utility Commissioners (NARUC). At the same time, these entities also filed suit in the US Court of Appeals for the District of Columbia seeking to prevent DOE from withdrawing the License Application on legal grounds. The suits contend that the Nuclear Waste Policy Act of 1982, as amended, and the Yucca Mountain Development Act (the resolution passed by Congress overriding Nevada's veto of the President's site recommendation in 2002 and authorizing DOE to apply for a license from the NRC to construct the facility) prohibit DOE from arbitrarily withdrawing the application and require NRC to carry the proceeding through to a decision.

The Construction Authorization Board initially sought to defer decision-making to the courts. On April 6, 2010, it issued an order postponing its decision on the new petitions to intervene and DOE's Motion to withdraw the license application until the appeals court made its decision. On April 23, 2010, however, the full NRC Commission formally reversed the Board's ruling and directed the CAB to hear arguments regarding the motion to withdraw and to make a decision by June 1, 2010.

The CAB held another formal hearing in Las Vegas on June 3rd and 4th to hear arguments regarding DOE's motion to withdraw the LA. The new petitioners were allowed to participate in this hearing, even though their requests for intervention had not been granted at that time.

On June 29, 2010, the Construction Authorization Board issued a ruling formally granting the petitions of the five new intervenors to participate in the licensing proceedings and formally denied DOE's motion to withdraw the License Application. That decision is being appealed to the full Nuclear Regulatory Commission by DOE, the State of Nevada and several other interveners, asking that the Commission reverse the CAB decision and grant DOE's motion to withdraw the license application. In the meantime, the DC Circuit Court of Appeals has

suspended action on the lawsuit seeking to prevent DOE from terminating the Yucca Mountain program brought by Washington, South Carolina and others, pending a final decision by NRC on this appeal.[5]

As of the publication of this report, the future of the Yucca Mountain project and the federal high-level radioactive waste program remains very uncertain. Despite the decision of the NRC licensing board denying DOE's motion to withdraw the Yucca Mountain license application, DOE is moving ahead with actions indicative of terminating the program. As of October 1, 2010, the Office of Civilian Radioactive Waste Management (OCRWM), the organization within DOE responsible for the Yucca Mountain program, has been formally disbanded, with responsibility for waste disposal activities transferred to DOE's Office of Nuclear Energy and decisions regarding alternative approaches for managing waste deferred pending the recommendations of the Blue Ribbon Commission on America's Nuclear Future.

The Blue Ribbon Commission on America's Nuclear Future

In January 2010, President Obama issued an executive order establishing a Blue Ribbon Commission (BRC) on America's Nuclear Future charged with identifying alternatives for managing spent nuclear fuel and high-level waste. The BRC has 15 members – appointed by the President - representing a wide range of expertise and diverse backgrounds. It is co-chaired by two well respected individuals, former congressman and vice chair of the 9/11 Commission, Lee Hamilton and former National Security Advisor, Brent Scowcroft.

The BRC is charged with conducting a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including alternatives for the storage, processing, and disposal of civilian and defense spent nuclear fuel, high-level waste, and materials derived from nuclear activities. Specifically, the Commission would provide advice and make recommendations for a new plan to address these issues. In providing direction to the BRC, Energy Secretary Chu specifically instructed the Commission that it was not being charged to address the Yucca Mountain project and that Yucca Mountain was off the table, having been determined to be "unworkable." The BRC is charged with addressing a variety of issues, including:

a) Evaluation of existing fuel cycle technologies and R&D programs. Criteria for evaluation should include cost, safety, resource utilization and sustainability, and the promotion of nuclear nonproliferation and counter-terrorism goals.
b) Options for safe storage of spent nuclear fuel while final disposition pathways are selected and deployed;
c) Options for permanent disposal of spent fuel and/or high-level nuclear waste, including deep geological disposal;

[5] Should NRC uphold the licensing boards' decision denying DOE's motion to withdraw the application, the court case would essentially become moot. On the other hand, were NRC to overturn the CAB ruling and permit DOE to withdraw the application, it is almost certain that the court case would go forward.

d) Options to make legal and commercial arrangements for the management of spent nuclear fuel and nuclear waste in a manner that takes the current and potential full fuel cycles into account;
e) Options for decision-making processes for management and disposal that are flexible, adaptive, and responsive;
f) Options to ensure that decisions on management of spent nuclear fuel and nuclear waste are open and transparent, with broad participation;
g) The possible need for additional legislation or amendments to existing laws, including the Nuclear Waste Policy Act of 1982, as amended; and
h) Any such additional matters as the Secretary determine to be appropriate for consideration.

The BRC has hired staff and established three subcommittees[6] to address specific areas of importance in evaluating alternatives and formulating recommendations for future waste management solutions. The BRC is scheduled to issue a draft report in June 2011 and a final report in January, 2012.[7] The Nevada Agency for Nuclear Projects was asked to testify at and participate in BRC meetings by BRC commissioners and staff.

Transportation Developments Related to the Federal High-Level-Waste Program

Transportation of spent nuclear fuel and high-level radioactive waste within Nevada and nationally remains a major concern and a key driver of impacts that would be associated with the proposed Yucca Mountain facility. Over the years, potential impacts of a prospective Yucca Mountain nuclear waste shipping campaign have been a major concern and topic of extensive study by the Commission and the Agency. Regardless of what alternatives are identified for managing spent fuel and HLW in the future, the development of a safe, secure, and publically acceptable transportation system must be a priority at the national level. To date, no such system exists and the current state of planning for

Transportation of spent nuclear fuel and high-level radioactive waste within Nevada and nationally remains a major concern and a key driver of impacts that would be associated with the proposed Yucca Mountain facility.

[6] The three BRC subcommittees are as follows: The Disposal Subcommittee, which deals with the issue of permanent disposal alternatives; the Reactor and Fuel Cycle Subcommittee, which addresses alternative waste management options such as reprocessing; and the Transportation and Storage Subcommittee, which deals with spent fuel and HLW transportation and shipment safety matters as well as at-reactor and centralized interim storage alternatives. The subcommittees are tasked to address specific questions: (1) "How can the U.S. go about establishing one or more disposal sites for high-level nuclear wastes in a manner that is technically, politically and socially acceptable?" (Disposal); (2) "Do technical alternatives to today's once through fuel cycle offer sufficient promise to warrant serious consideration and R&D investment, and do these technologies hold significant potential to influence the way in which used fuel is stored and disposed?" (Reactor & Fuel Cycle); and (3) "Should the US change the way in which it is storing used nuclear fuel and high-level waste while one or more final disposal locations are established?" (Transportation & Storage).
[7] Detailed information on the BRC's charter and activities can be found on the BRC's web site at: http://www.brc.gov/ .

large numbers of spent fuel and HLW shipments is wholly inadequate.

Of the State of Nevada's 229 contentions or challenges to DOE's findings and conclusions in the DOE's Yucca Mountain license application, 16 address key repository transportation issues where DOE failed to adequately comply with the requirements of the National Environmental Policy Act (NEPA), including:

- Impacts of Transportation Sabotage & Severe Accidents (7 contentions);
- Impacts of Rail Access, Construction & Operation (5 contentions);
- Impacts of Transportation Routine Radiation Exposures (2 contentions);
- Impacts of Transportation, Aging and Disposal (TAD) Container Shipment Numbers (1 contention);
- Impacts of Representative HLW Shipping Routes (1)

These contentions address a wide range of issues associated with the potential shipment of spent fuel and high-level waste to a prospective Yucca Mountain facility. For the most part, the Agency found that DOE, in its license application and associated NEPA documents, had not adequately addressed transportation risks and safety concerns raised by Nevada, western states and other stakeholders over the past two decades and that the Yucca Mountain license application is materially deficient as to the transportation aspects of the proposed facility..

Since enactment of the Nuclear Waste Policy Amendments Act and adoption of Assembly Concurrent Resolution 8 by the Nevada Legislature in 1987[8], the State of Nevada has made numerous recommendations to DOE regarding nuclear waste transportation safety and security. Nevada has consistently recommended the ten measures summarized in the figure below as the basis for any safe, secure and workable high-level radioactive waste transportation program.

- **Oldest Fuel First**
- **Mostly Rail (65-75%)**
- **Dual-Purpose Casks**
- **Dedicated Trains**
- **Full-scale Cask Testing (Regulatory & Extra-regulatory)**
- **NEPA Process for Selection of Rail Spur**
- **WIEB "Straw Man" Routing Process**
- **Sec 180(c) Program Rulemaking**
- **State Regulatory Enhancements (Safety & Perception)**
- **Terrorism and Sabotage Concerns**

State of Nevada Transportation Safety and Security Recommendations

[8] ACR 8 required the Agency for Nuclear Project to evaluate transportation requirements and impacts associated with the proposed Yucca Mountain repository project. The report that was produced has served as a blueprint for the State of Nevada in addressing spent nuclear fuel and high level waste transportation issues.

These measures emphasize a comprehensive approach to risk assessment, risk management, and risk communication; development of a preferred transportation system for repository shipments; full-scale, physical testing of shipping casks; and accident prevention and emergency response:

Oldest Fuel First: Nevada has recommended that DOE ship the oldest fuel first, or at least ship older fuel first. The National Academy of Science (NAS) and the Government Accounting Office (GAO) also recommend shipping older fuel first. Shipping fuel 50 years out of reactor, compared to shipping 5-year-cooled fuel, could reduce radiological hazards 65-85 percent.

Modal Mix: Nevada has recommended that DOE select rail as the preferred mode of transportation, acknowledging the serious impediments to developing rail access to Yucca Mountain and to 24 of the 76 shipping sites. Based on shipping site current capabilities, the share of SNF that could realistically be shipped by rail may be 65-75 percent, not the 90 percent projected by DOE. DOE must plan for large numbers of truck shipments under the "mostly rail" shipment scenario.

Dual-Purpose Casks: Nevada has recommended that DOE base its transportation system on use of dual-purpose (transportable storage) casks of a standardized design, with a range of capacities resulting in loaded cask weights of about 125, 100, and 70 tons. In 1995, Nevada endorsed the DOE proposal for a similar approach using a multi-purpose canister (MPC) system for storage and transport.

Dedicated Trains: Nevada has recommended that DOE use dedicated trains for all rail shipments. Until DOE commits to use dedicated trains only, DOE routing studies and risk analyses must evaluate use of both dedicated and general freight rail shipments.

Cask Testing: Nevada has recommended that DOE and/or NRC conduct a meaningful full-scale testing program. DOE or NRC should conduct full-scale regulatory tests on each cask design (or in some cases of similar designs, test one cask from each representative grouping). DOE or NRC should also conduct a combination of extra-regulatory, full-scale testing (fire), scale model testing, component testing, and computer simulations to determine cask failure thresholds. In addition, DOE and/or NRC must ensure meaningful stakeholder participation in all aspects of the cask testing program. This is a safety issue, not a public relations demonstration.

Shipment Routes: Nevada has recommended that DOE select routes for the national transportation system following a three-step process proposed by the Western Interstate Energy Board (WIEB): DOE would designate "straw man" routes, preferably in the Yucca Mountain FEIS or another NEPA document; WIEB member states would individually and collectively evaluate the DOE routes, and then designate preferred routes on a regional basis; DOE would then formally adopt the routes identified by WIEB, and designate these routes (allowing exceptions for use of designated alternative routes in emergency situations) in DOE contracts with rail and highway carriers.

Section 180(c): Nevada has recommended that DOE implement the transportation planning and emergency response training program, required under Section 180(c) of the NWPAA, through formal rulemaking. Absent rulemaking, the State of Nevada believes that congressional action might be needed to implement the program, as was the case with the Waste Isolation Pilot Plant (WIPP) DOE-State cooperative transportation planning program.

State, Local, & Tribal Regulation: Nevada has recommended that DOE support state regulatory enhancements to manage transportation risks and address public perception of transportation risks. These would include, but not be limited to, port-of-entry inspections and state escorts for DOE shipments at DOE expense. States, in conjunction with local governments, may also impose seasonal, day-of-week, and time-of-day restrictions on DOE to address unique local conditions. Tribal governments may also regulate DOE shipments.

"DOE's National Transportation Plan is hardly worthy of the name. It lacks specificity, continues the fragmentation and 'stove-piping' of transportation system components, and hinders rather than promotes a systems approach to planning for and managing SNF and HLW shipments. It is neither 'national' in its orientation and concept nor is it in any sense a useful or meaningful 'plan'".

Terrorism and Sabotage: Nevada has recommended that DOE address acts of sabotage and terrorism against repository shipments. DOE has acknowledged, in the FEIS and in the SEIS, the potential vulnerability of shipments to such attacks. Analyses by Nevada contractors have concluded that the releases and consequences of such attacks could be many times greater, resulting in catastrophic cleanup and recovery costs.[9] DOE needs to fully address terrorism issues in development of repository transportation operational protocols.

In 2009, DOE released a long-anticipated draft of its National Transportation Plan (NTP). That Plan was expected to finally, after more than two decades of work on DOE's part, provide a comprehensive and detailed depiction of just how DOE proposed to ship spent fuel and high-level waste to a repository from facilities throughout the country. Instead, the so-called "plan" produced by DOE was little more than an outline, with little or no specificity and with major questions unanswered and uncertainties unresolved.

In extensive comments submitted to DOE regarding the draft NTP, the State of Nevada found DOE's work on the entire range of transportation planning to be woefully inadequate. The State concluded that "the current draft of what DOE terms its National Transportation Plan is hardly worthy of the name. It lacks specificity, continues the fragmentation and 'stove-piping'

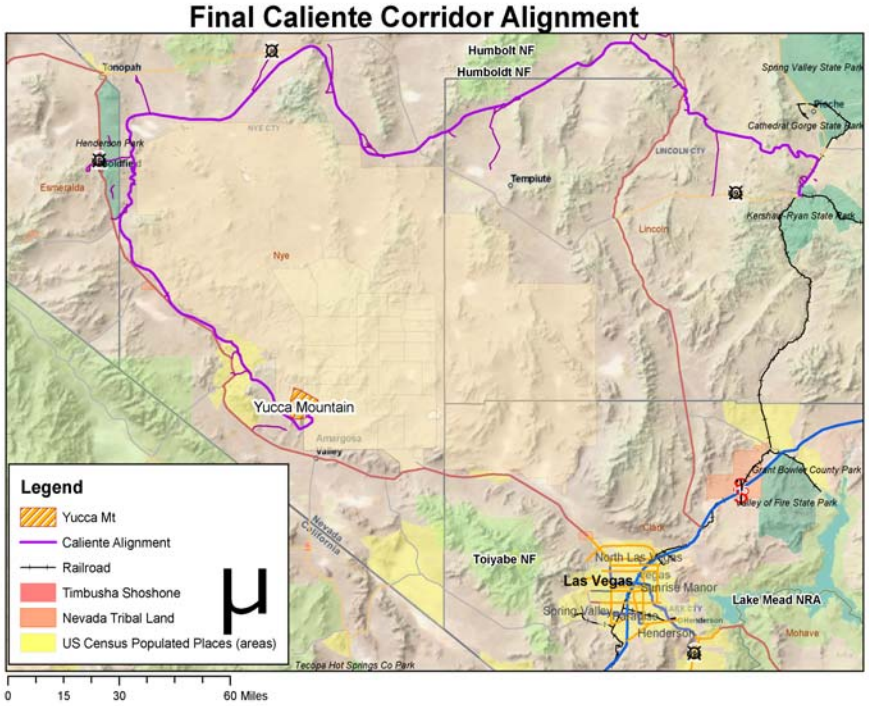
[9] Resnikoff and Travers, Potential Consequences of a Successful Sabotage Attack on a Spent Fuel Shipping Container: Updated Analysis (November 2008) http://www.state.nv.us/nucwaste/news2008/pdf/rwma0810sabotage.pdf

of transportation system components, and hinders rather than promotes a systems approach to planning for and managing SNF and HLW shipments. It is neither 'national' in its orientation and concept nor is it in any sense a useful or meaningful 'plan'."[10]

In summary, despite years of effort and extensive input from Nevada, state regional groups, and a wide range of stakeholder groups, organizations and entities, DOE has made scant progress over more than 20 years in addressing, much less resolving, key transportation issues.

Status of DOE's Application for a Yucca Mountain Rail Line

Since DOE's decision to terminate the Yucca Mountain program and petition to withdraw the license application, there has been no further action on DOE's application to the U.S. Surface Transportation Board (STB) for approval to construct a rail line to Yucca Mountain. In 2008, DOE filed an application with the STB for a Certificate of Public Convenience and Necessity (CPCN) providing authorization to construct and operate a rail line to Yucca Mountain along the proposed Caliente rail corridor. In conjunction with that application, DOE prepared two NEPA documents dealing with the proposed rail spur. The Agency worked with the Attorney General's Office and its contract attorneys to develop and submit a petition asking STB to suspend or terminate the proceeding dealing with DOE's application, citing the Administration's decision not to go forward with Yucca Mountain and the significant budget cuts proposed for the program.



The Secretary of Energy's decision to move for withdrawal of the Yucca Mountain license application and the Obama Administration's directive that DOE not pursue any Yucca Mountain activities other than those related to the LA withdrawal has meant that DOE has not pressed its case for approval to construct the proposed Caliente rail spur. The STB proceeding appears to be in abeyance (although no formal action has been taken to suspend the proceeding).

[10] The full text of Nevada's comments on DOE National Transportation Plan can be found at: http://www.state.nv.us/nucwaste/news2009/pdf/nv090421ntp.pdf .

DOE has not, as of the date of this report, withdrawn the CPCN application that is pending before the STB.

As part of its effort to move ahead with the proposed Caliente rail line, DOE had submitted applications to the State Water Engineer for a series of water rights along the proposed route. The water being requested was to be used in the construction and operation of the proposed rail spur. In 2010, DOE advised the Water Engineer that it was withdrawing those applications in compliance with Administration directives that DOE cease all Yucca Mountain activities other than those needed for shutting down the project and responding to the requests from the NRC licensing proceeding.

Chapter 2 - Key Lessons Learned from Yucca Mountain and the Failed Federal HLW Program

Why Yucca Mountain Failed

From Nevada's perspective, DOE did almost nothing "well" with respect to its implementation of the Yucca Mountain program. Early on – at least from 1986 and possibly earlier - DOE had predetermined that Yucca Mountain had to be found suitable as a repository at any cost, and all of the work that went into characterizing the site was designed to support that determination. When potential disqualifying conditions were found, DOE either changed the regulations or ignored the findings (or trivialized them as not important).

DOE was also subject to the actions of Congress (although it was difficult to differentiate at times whether Congress was directing DOE or DOE was manipulating Congress). If Congress, in 1986 -1987, had held DOE's feet to the fire and required it to implement the Nuclear Waste Policy Act as originally intended, without the predetermined outcomes and free from political influence, it is possible that the Act, flawed as it was, might have yielded a successful repository site, albeit not Yucca Mountain. However, that did not happen, and the rest is history.

The Forced Nature of the Siting Process

Yucca Mountain failed for many reasons, but a critical element was unquestionably the forced nature of the siting process. In 1987, when Congress directed that Yucca Mountain be the only site to be studied, DOE used that directive as the basis for pushing ahead with the project even when the data showed serious flaws in the site and in the face of strong and determined opposition from the state.

While the Nuclear Waste Policy Act did contain a provision whereby Nevada, theoretically could veto the site following the President's recommendation to develop it as a repository, the notice of disapproval contained in the Act was essentially meaningless, because the bar was (intentionally) set so high that a small state like Nevada could not be expected to obtain the two-thirds of the votes in both the House and Senate needed to sustain the State's veto in the face of an administration determined to force the site on the State and a Congress anxious not to risk exposing members' states to a new siting effort.

If DOE had been required to obtain the State's informed consent to continue with the project, Yucca Mountain would have been disqualified years earlier (saving billions of dollars and years of effort) and DOE would have had to move on to identify a truly suitable location. In reality, however, there was no incentive for DOE to work with or listen to the State, since DOE

believed all along that it would be able to force the decision on Nevada, regardless of concerns about the site.

Yucca Mountain was a Bad Site from the Beginning

Very early on, it was known that the Yucca Mountain site had serious geotechnical problems, but DOE ignored or trivialized them and proceeded as if its mandate was to do whatever it took to make Yucca Mountain work. The focus of DOE's work on the project changed after the 1987 amendments to the Nuclear Waste Policy Act singled out Yucca Mountain as the sole site for characterization. DOE went from asking, "Is Yucca Mountain a suitable site?" to "What do we need to do to make the site work?" And that quickly evolved to, "What regulations and standards have to be changed?" and "How do we engineer the facility so as to try to overcome the site's physical flaws?" The "science" at Yucca Mountain deteriorated as time went on and more and more unfavorable findings surfaced. DOE's site characterization program appeared to be designed NOT to identify anything that might disqualify the site.

Yucca Mountain failed for many reasons, but a critical element was unquestionably the forced nature of the siting process. In 1987, when Congress directed that Yucca Mountain be the only site to be studied, the focus of DOE's efforts went from asking, "Is Yucca Mountain a suitable site?" to "What do we need to do to make the site work?" And that quickly evolved to, "What regulations and standards have to be changed?" and "How do we engineer the facility so as to try to overcome the site's physical flaws?"

This approach led to a series of ever-more-exotic engineering "fixes." For example, the current license application includes covering all the waste canisters with 11,500 titanium drip shields to protect them from rock fall and highly corrosive groundwater. But the drip shields themselves (estimate to cost $12 billion or more) are only proposed to be installed 80 to 100 years after the waste is put into the mountain, using yet-to-be developed robotics due to the extreme thermal and radiological environment that would exist within the emplacement tunnels.

Despite this, potentially disqualifying conditions were revealed at the site (i.e., fast groundwater pathways, unacceptably high level potential for escaping radioactive gasses, recent volcanism, high levels of seismicity, etc.). To get around this, DOE petitioned Congress to exempt the site from health and safety regulations and then scrapped its own site evaluation guidelines altogether.

Congress shares a large portion of the blame for the failure of the current federal high-level radioactive waste program to produce a repository. The original Nuclear Waste Policy Act of 1982 was a complex and cumbersome law that sought to balance a variety of competing and often conflicting interests. But the Act represented significant agreement on the part of diverse affected parties that might have had a chance of succeeding if Congress had not gutted the Act in

response to political considerations in 1987 [11] and, instead, held DOE's feet to the fire and required DOE to implement the original Act as intended.

DOE – The Wrong Entity to Implement the Program

The federal government has been actively trying to find a workable solution to the problem of spent fuel and high-level waste for over 50 years. Ironically, the mistakes that doomed earlier attempts to site waste disposal and/or storage facilities continued to dominate DOE's efforts with regard to Yucca Mountain. In the 1960s, the Atomic Energy Commission (DOE's earliest predecessor agency) moved aggressively to develop an abandoned salt mine in Lawrence, Kansas as a permanent disposal facility, only to be forced to abandon the effort due to shoddy scientific work and failure to obtain support from the host state. Attempts by AEC's successor agency, the Energy Research and Development Administration (ERDA) to site an above-ground centralized storage facility met a similar fate for almost identical reasons.

The U.S. Department of Energy was probably the wrong entity to implement the federal high-level radioactive waste program and placing the program within DOE may have doomed it from the start. The Alternative Means of Financing and Managing (AMFM) Panel[12], as early as 1984, recommended that the high-level waste management program be removed from DOE and set up as a quasi-governmental corporation to insulate it from political influences and to provide the program with stability and continuity over the long period of time that would be required to site, construct and operate one or more repositories.

The original Nuclear Waste Policy Act of 1982 was a complex piece of legislation that sought to balance numerous competing interests and constituencies. The very character of DOE, with its culture of secrecy, its 'we know best' decision-making, its schedule-driven approach, and its inability to work in a cooperative manner with states and communities, made it the worst possible entity to implement a program that required the level of sophistication needed to effectuate the difficult compromises embodied in the Act.

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[11] During the election cycle of 1986, the Reagan Administration, responding to political pressure from eastern states that had potential sites being examined for a second repository, directed DOE to suspend the second repository program (an important component in the Act to insure regional equity). In 1987, powerful states with potential first repository sites (esp. Louisiana, Texas and Washington) successfully managed to gut the carefully crafted selection process for the first repository, get their states off the hook and single out Nevada's Yucca Mountain based on political considerations [i.e., Nevada's political weakness vs. the clout of Senate Energy Committee Chairman J. Bennett Johnston (LA), House Speaker Jim Wright (TX) and House Majority Leader Tom Foley (WA)].

[12] Section 303 of the Nuclear Waste Policy Act of 1982 required the Secretary of Energy "to undertake a study with respect to alternative approaches to managing the construction and operation of all civilian radioactive waste management facilities, including the feasibility of establishing a private corporation for such purposes." The section was in response to concerns, even as early as 1982 and before, that housing the waste program in a federal agency would doom it to failure due to the undue influence of politics and the vagaries of changing administrations. The AMFM Panel released its report, "Managing Nuclear Waste – A Better Idea," in December 1984, which concluded that "[t]he Panel's preferred long-term alternative to the Office of Civilian Radioactive Waste Management (OCRWM) for managing the nation's high-level radioactive waste program is a public corporation chartered by Congress."

In Nevada, DOE created a hostile atmosphere almost from the beginning by trying to interfere with the state's Yucca Mountain oversight program, and insisting on approving all activities the state proposed to implement. As early as 1984, the State was forced to go to court to secure its independent oversight role. The court strongly admonished DOE, finding that allowing DOE to approve or disapprove the state's specific oversight work would be akin to "permitting the fox to guard the chicken coop." Even after the court ruling, DOE continued to interfere with Nevada's oversight by withholding, delaying and otherwise impeding needed funds, hampering site access, and making it difficult for Nevada personnel to gain access to needed data and information.

Because of the heavy-handed manner in which DOE has implemented the Yucca Mountain program and the history of instability in leadership, mismanagement, faulty science and data irregularities, and a host of other serious problems over the years, it would be next to impossible for a similar siting program implemented by DOE to obtain the level of trust and confidence necessary for a successful program.

Key Lessons for the Future

It is difficult to see how a favorable outcome could have resulted from DOE's implementation of the original NWPA. Given the nature of DOE and its role as a federal cabinet agency, DOE was/is just too amenable to political influences and is constrained by its own history and culture – i.e., the ingrained tendency towards secrecy and a "Decide-Announce-Defend" approach to whatever it undertook. However, the Yucca Mountain experience does provide useful lessons for future nuclear facility siting efforts.

Any Future Siting Process Must Be Voluntary, Scientifically Credible,
And Based on Strict, Objective, and Technically Rigorous Criteria

The two most important lessons to be derived from the failed Yucca Mountain program are inextricably interrelated. First, a successful facility siting program must be fully voluntary and must obtain the fully informed consent of the host state, tribe (if applicable) and local community. If there is anything the failed Yucca Mountain experiences teaches, it is that forcing a site or facility on an unwilling state will not work.

A successful siting program must be completely open and transparent, with a full participatory role for the host state, and with the process structured so that a potential host state has the right to opt out at any time. After Nevada's experience with the heavy-handed approach to forced siting employed by DOE and the federal government with respect to the Yucca Mountain project, it would be difficult, if not impossible, to find another state willing to engage with the government in a siting effort without such a guarantee.

It is not sufficient to obtain the support of only the local host community. Because of the nature of a repository or other nuclear facility and its impact on the state (and perhaps the region), and because of the significant impacts and implications of the major nuclear materials transportation campaign that would unavoidably be associated with it, obtaining the support and consent of the state is of paramount importance. (The experience with the Private Fuels Storage

facility in Utah is also instructive in this regard.) Seeking to pit economically desperate local communities against the state, as DOE did in Nevada, only engenders further animosity and is counterproductive.

Gaining the confidence and trust of a state and community requires confidence in the quality and integrity of the scientific work regarding any given site. This is indispensible to obtaining the state's and community's consent. The second key lesson, therefore, is that any future siting effort must be based on and motivated by irrefutably sound science. It is crucial that a repository siting program be viewed and implemented as a research effort, not as an engineering project. The question to be addressed must be, "Is this a safe and suitable site?" - Not, as in the case of Yucca Mountain, "How can we make the site work in spite of all its flaws?"

A scientifically credible repository siting effort must have as its foundation objective and rigorous criteria against which the geotechnical suitability of a site would be evaluated. The criteria must be established in advance of the siting effort and not structured so as to apply only to specific sites. The application of the criteria to candidate sites must be objective and above reproach, and criteria cannot be changed based on conditions found when studying or characterizing various sites.

The two most important lessons to be derived from the failed Yucca Mountain program are inextricably interrelated. First, a successful facility siting program must be fully voluntary and must obtain the fully informed consent of the host state, tribe (if applicable) and local community. Second, any future siting effort must be based on and motivated by irrefutably sound science.

Lessons from DOE's Second Repository Program of the 1980s

There is reason to believe that a truly objective site selection process is achievable, but to be successful it must be insulated from the political process. Prior to 1986, DOE's program for screening sites for a second repository (the program that was unilaterally terminated by DOE for political reasons in '86 and eliminated altogether by Congress in the Amendments Act of 1987) was a technically and scientifically sound approach to identifying potentially suitable repository locations.

The methodology employed by DOE for identifying potential second repository sites was essentially sound and very likely could have resulted in the identification of potentially suitable sites[13]. However, that effort was derailed in 1986 when key eastern states where possible sites were located prevailed on the Administration to stop the screening project during the 1986 election cycle. The second repository program was the last and only effort by DOE to pursue a scientifically based site screening and site evaluation approach.

[13] Potentially suitable sites means sites that are shown to be geotechnically and scientifically appropriate for long term isolation of spent fuel and high-level radioactive waste. It does not imply that DOE's otherwise heavy-handed, forced siting approach with respect to potential host states would have been any more effective in a second repository program than it was at Yucca Mountain.

Chapter 3 - What the Future Holds: Implications for Nevada, the Agency and the Commission

The Commission finds that the decision by the Secretary of Energy to terminate the Yucca Mountain program and withdraw the license application pending before the NRC was appropriate, necessary, and more than justified by the weight of evidence indicating that the Yucca Mountain site is unsafe and unsuitable for a high-level radioactive waste repository. Energy Secretary Chu found that the Yucca Mountain project is unworkable, and by continuing to blindly pursue it in the face of mounting problems (as past Administrations had done) would be much worse for the commercial nuclear power industry and the country than facing reality and moving aggressively to find workable alternative solutions.

At the time DOE moved to withdraw the Yucca Mountain license application, intervenors in the licensing proceeding had succeeded in filing some 299 contentions (serious technical objections) admitted by the NRC administrative law judges. This was by far the largest, most complex and most contested proceeding in NRC's history. The contentions challenged the very heart of DOE's assertion that Yucca Mountain could contain the waste for the extremely long time period required. It was becoming obvious in the early stages of the proceeding that DOE's arguments were not faring well.

> ***The Commission finds that the decision by the Secretary of Energy to terminate the Yucca Mountain program and withdraw the license application pending before the NRC was appropriate, necessary, and more than justified by the weight of evidence indicating that the Yucca Mountain site is unsafe and unsuitable for a high-level radioactive waste repository.***

It is by no means a certainty that DOE would have been able to obtain a license to construct a repository at Yucca Mountain. In fact, given the nature and seriousness of the contentions filed, a rejection of DOE's application by the NRC licensing board had to be considered a strong possibility. The country and the industry could be far worse off by proceeding through a drawn out licensing proceeding only to find, perhaps 10 or more years from now, that the application was rejected. By finding the Yucca Mountain site unworkable, Secretary Chu acknowledged reality and took the necessary step of moving past Yucca Mountain towards technologically sound and workable alternatives.

The shift away from the narrow focus on geologic disposal and Yucca Mountain to forward-looking technologies like dry storage, reprocessing and transmutation would, in the long run, be extremely beneficial for the nation and for the nuclear power industry. Secretary Chu's

approach in creating the new Blue Ribbon Commission on America's Nuclear Future has the potential to advance the promise of nuclear power as a clean, reusable and inexhaustible energy source.

Politics and the Federal High-Level Radioactive Waste Program

In the years leading up to the enactment of the original Nuclear Waste Policy Act of 1982, there was an implicit acknowledgement that, in order to succeed, the HLW program would have to be insulated to a significant degree from political influences. The compromises involving regional equity, the requirement for three fully characterized sites, the focus on specific and technically based site selection criteria, and the creation of a new entity for implementing the program (the Office of Civilian Radioactive Waste Management) were all, in some way, related to this attempt at creating separation from political manipulation of the process. Ironically, however, the very nature of the organization and the federal department it was made a part of, virtually guaranteed that political considerations would ultimately overwhelm the effort.

Less than three years after the passage of the Act, election year politics eviscerated the scientific process envisioned by the original legislation. In 1986, fearing reaction in key congressional races during the off-year elections in eastern states where the second repository site search was underway, the Administration unilaterally ordered a halt to the program. At the same time, DOE's first repository program was under attack for having pre-selected sites in Nevada and Washington instead of conducting the objective, scientifically-based screening called for in the Act. The entire federal program quickly fell into chaos and conflict.

In late 1986, Congress once again stepped in and sought to fix the program. Instead of remedying it, however, Congress acted in the most politically expedient manner possible. It legitimized DOE's abandonment of the second repository program and gutted the carefully crafted process for selecting a first repository, directing by fiat that only one site was to be studied as a possible repository location – Yucca Mountain in Nevada.

Throughout the next two decades, politics continued to trump science within the federal program. In 1992, when evidence began to mount regarding levels of radioactive emissions that would cause Yucca Mountain to be disqualified, Congress again stepped in and directed the Environmental Protection Agency (EPA) to promulgate radiation exposure limits specifically tailored to just the Yucca Mountain site, insuring that the site could be shown to meet them.

In the 1990s, it became apparent that Yucca Mountain could not meet the requirement for groundwater travel time that was a disqualifying condition in the site selection guidelines specified by the original NWPA and established by DOE in 1985. DOE, with Congress' blessing, simply abandoned the original guidelines in favor of a completely new assessment approach that allowed the troublesome site condition to be hidden in a massively complex set of performance calculations.

Today, politics continue to be the preeminent factor in the Yucca Mountain program. As noted in the Commission 2008 report, considerable attention was given to the Yucca Mountain

issue during the 2008 presidential election in the strongly contested Nevada caucuses that were held very early in the process (February 2008). All the major Democratic contenders pledged to terminate the Yucca Mountain project if elected. During the general election campaign, candidate Obama repeatedly voiced skepticism about the need for the Yucca Mountain project and the wisdom of going forward with it in the face of fierce opposition on the part of the State.

In 2009, the new Energy Secretary announced that the Yucca Mountain project was 'unworkable' and that DOE was taking steps to terminate the program. In early 2010, DOE moved to withdraw the license application that was pending before the NRC and the President established the Blue Ribbon Commission to identify alternative approaches for managing spent fuel and high-level waste.

As of the publication of this report, the fate of Yucca Mountain remains very much in doubt, despite the current Administration's decision to terminate the project. It is possible that, based on actions by the courts and the outcome of the 2010 elections, decisions could be made resurrecting the Yucca Mountain program and restarting the dormant licensing proceeding. Such a possibility would require intensive efforts by the State to quickly and substantially ramp up efforts to again challenge the Yucca Mountain license application before the NRC.

The End - Or Just Another Phase in the Political History of Yucca Mountain?

While the Obama Administration's decision to terminate the Yucca Mountain program and withdraw the license application – and subsequent actions to eliminate funding for the program, dismantle the Office of Civilian Radioactive Waste Management and phase out all work on the project – might be seen as clear indications of Yucca Mountain's demise, nothing in this program can ever be that clear cut. Immediately following the Energy Secretary's announcement of DOE's intention to withdraw the license application, the states of Washington and South Carolina together with Aiken County, South Carolina filed suit in the federal court of appeals to prevent DOE from terminating the program. Additional parties subsequently joined in these efforts to oppose the license application withdrawal. These same entities also petitioned to be admitted as parties to the NRC licensing proceeding and filed objections to DOE's motion to withdraw the application.

In July 2010, after a series of petitions, responses, motions and rulings by the Yucca Mountain licensing board and the full NRC, the licensing board denied DOE's motion to withdraw the license application. That ruling was appealed to the full Commission by DOE, the State of Nevada, and several other parties to the proceeding. As of the date of this report, a decision by the NRC whether to sustain or overturn the licensing board ruling is still pending. Regardless of the outcome of the NRC's decision, it is almost certain that a final determination regarding DOE's ultimate right to withdraw the Yucca Mountain license application would be made by the courts, with the case potentially going all the way to the U.S. Supreme Court before a final determination is made.

As if the current state of affairs is not confusing enough, the fate of Yucca Mountain is also inextricably tied to the 2010 congressional elections and the federal budgeting process. The Administration is proposing to eliminate funding for the Yucca Mountain program in its FY 2011 budget and has directed DOE to act accordingly in carrying out activities for FY 2011 and subsequent years. The Administration's proposed FY 2011 budget for the Department of Energy contains no funding for the Yucca Mountain program other than that required to responsibly close down the program. As of the date of this report, the Senate Energy Appropriations Committee has voted a FY 2011 Energy and Water Development Appropriation Bill out of committee that contains no funding for continuing the Yucca Mountain project, but the measure has not been acted on by the full Senate. The House of Representatives appropriations committee has yet to act on the House version of the legislation. DOE is operating under a continuing resolution through December 3, 2010 that provides incremental funding for the Department at FY 2010 level. However, the Office of Management and Budget has directed that no continuing resolution funds can be used for programs or projects for which a Senate or House committee has eliminated funds for 2011. Ultimately, the level of funding for the Yucca Mountain project for FY 2011 would be decided in conference once both full House and Senate have acted on their respective measures. The issue is expected to be heavily influenced by the outcome of the 2010 congressional elections.

Congress has yet to act on the FY 2011 budget and it remains uncertain just what funds, if any, would be available for the project in FY 2011. The Energy and Water Development Appropriations measure that was voted out of committee in the Senate, contains funding in the amount of $2.5 million for the Agency for Nuclear Projects oversight of Yucca Mountain shut down activities, but only if the Senate language is carried forward into the final appropriations bill.

As of the publication of this report, the fate of Yucca Mountain remains very much in doubt, despite the current Administration's decision to terminate the project. It is possible that, based on actions by the courts and the outcome of the 2010 elections, decisions could be made resurrecting the Yucca Mountain program and restarting the dormant licensing proceeding. Such a possibility would require intensive efforts by the State to quickly and substantially ramp up efforts to again challenge the Yucca Mountain license application before the NRC.

If, however, the decision to terminate the project is sustained, much work on the part of the State of Nevada would be required to oversee the shut down and decommissioning of the site and to oversee and participate in the work of the Blue Ribbon Commission to assure Nevada's interests are protected with respect to future waste management alternatives that might be identified.

The re-election of Senate Majority Leader Harry Reid in the November congressional elections, while critically important to Nevada's efforts to oppose the Yucca Mountain program, does not of itself assure that the project would be terminated as the Administration proposes. The fact that the House of Representatives would be in Republican control for the next Congress likely means that key committee and subcommittee chairmen (especially those dealing with

appropriations on the House side) would be much more sympathetic to Yucca Mountain. That could result in significant differences between Senate and House appropriation bills. Conflicting provisions of appropriations measures would have to be reconciled through the conference committee process. Such a scenario could make it more difficult for Senator Reid to fully zero-out funding for the program in future federal budgets and complicate the Administration's efforts to cleanly end the project.

CHAPTER 4 – RECOMMENDATIONS OF THE NEVADA COMMISSION ON NUCLEAR PROJECTS

Despite the U.S. Department of Energy's decision to seek to withdraw the Yucca Mountain license application and the substantive steps DOE has taken to terminate the program as 'unworkable', the Commission finds the State of Nevada remains very much at risk due to the pervasive uncertainties that continue to characterize the federal program. The recommendations which follow are intended to assist the Governor and Legislature in navigating the confusing, conflicting, and highly uncertain circumstances that continue to define the Yucca Mountain project.

(1) The Governor and the Legislature must continue to reject any proposal to negotiate for benefits in exchange for agreeing to the Yucca Mountain project or that would have Nevada consider reprocessing and/or interim storage facilities at the site.

Discussion: In the wake of DOE's decision to withdraw the Yucca Mountain license application currently pending before the NRC and terminate the project, nuclear industry supporters and surrogates in Nevada have been urging state and local officials to consider negotiating for other nuclear facilities, such as reprocessing and interim storage projects. Their reasoning is that something should be salvaged from the failed Yucca Mountain program, and Nevada could reap significant rewards for agreeing to host such facilities. At the same time, these same factions would have the State re-think its opposition to a Yucca Mountain repository in exchange for a laundry list of ever-more-exaggerated benefits.

The siren call for negotiations is nothing new. Nuclear industry supporters and Yucca Mountain proponents have for years been urging Nevada's leaders to accept the inevitable and negotiate with the federal government for benefits in exchange for accepting the project. The industry has been attempting to use the fiction of large financial and other benefits as a wedge to fracture Nevada's united front of opposition to the program. Recently, due to the severe economic downturn impacting the State, there have been intensified efforts on the part of certain groups and industry surrogates urging negotiations, using the State's fiscal crisis as a rationale for seeking benefits from the federal government with respect Yucca Mountain or other nuclear facilities.

There are insurmountable problems with these calls for negotiation. First among them is the fact that the same geotechnical, transportation, environmental, and economic risk factors that made Yucca Mountain unsafe and unsuitable as a repository site also make it unsafe and unacceptable for other nuclear facilities. Second, there are no financial or other benefits to be had. The Nuclear Waste Policy Act provided that Nevada could have received $10 million per year before waste was emplaced at Yucca Mountain and $20 million annually after the facility was opened.

However, to receive even this petty amount, Nevada would have had to give up its right to object to the project and agree to cooperate with DOE in its development. The Nevada Attorney General has also determined that the act of entering into negotiations would signal Nevada's implied consent and seriously weaken and even cripple the State's ability to contest future decisions in the courts. Claims of significant amounts of money or other equally outlandish benefits in exchange for Yucca Mountain or any other related facility are simply false and designed to fend off the impending collapse of the Yucca Mountain program by securing this implied consent.

In terms of reprocessing facilities, the technology does not yet exist to allow this to be done either economically or without vast amounts of waste and contamination. The type of reprocessing being considered for the country in the future requires technology that would not be available for 50 years or more. Such facilities, if they ever do become feasible, certainly would not be of help for decades to come, economically or in terms of jobs creation, wherever they might safely be located. Reprocessing would also require 30,000 – 50,000 acre feet of water annually, water that is not available in southern Nevada, let alone at Yucca Mountain.

The Commission believes that it is critically important for the Governor and Legislature to continue to voice strong and unified opposition to the proposed Yucca Mountain repository and to resist any and all calls for negotiations involving reprocessing projects, spent fuel and high-level waste interim storage facilities, or other nuclear-related facilities.

(2) The Nevada Agency for Nuclear Projects continues to be vital to the State's ability to oversee the Yucca Mountain program and assure that Nevada's interests are protected with respect to the activities and subsequent recommendations of the Blue Ribbon Commission on America's Nuclear Future.

Discussion: Despite the significant progress made during the past two years towards terminating the Yucca Mountain project, major uncertainties remain as to the future of the program. Should the NRC or the federal court determine that DOE is not permitted to withdraw the Yucca Mountain license application now pending before the NRC, it is likely that there would be resumption of the full-blown licensing proceeding that has been suspended in recent months.

The Agency for Nuclear Projects has been overseeing the federal high-level radioactive waste program and the Yucca Mountain project over 27 years. It has developed information and expertise regarding the program that is unique and not available anywhere within or without state government. While the Nevada Attorney General is responsible for overseeing the legal aspects of the State's licensing efforts, it is crucial that the Agency continue to have the resources to provide the technical and policy support indispensible to a successful licensing intervention.

Intervening in a NRC licensing proceeding is a lengthy, extremely costly and resource intensive process. Like DOE, the State has been required to provide NRC with all of the documents, data and other materials it plans to use in licensing in a format compatible with NRC's licensing support network. The Agency for Nuclear Projects works with a wide range of scientists and technical experts (chemists, geologists, volcanologists, seismologists, transportation experts, and others) in carrying out the State of Nevada's licensing responsibilities and other oversight functions under the Nuclear Waste Policy Act.

The NRC licensing process itself is an extremely complex one, both legally and technically. NRC has established three (3) licensing boards which operate concurrently, requiring attorneys, Agency staff, and Agency technical experts to cover each one. The State of Nevada must be fully engaged in every step - from reviewing, commenting and challenging NRC licensing regulations, to participating in all licensing proceedings, hearings and other forums, to producing detailed technical analyses supporting contentions the State has raised relative to DOE's assertions about site performance, to substantive and procedural legal challenges to NRC's implementation of the process. The effort on the part of the Agency to effectively provide technical, scientific, and policy support in the NRC licensing proceeding is and would continue to be critical for protecting Nevada's interests and successfully opposing DOE's license application.

ATTACHMENTS

TECHNICAL AND SCIENTIFIC REASONS WHY DISPOSAL OF RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL AT YUCCA MOUNTAIN IS UNACCEPTABLE AND NOT ADEQUATELY PROTECTIVE OF HUMAN HEALTH AND SAFETY

THE 2010 STATE OF NEVADA YUCCA MOUNTAIN RISK SURVEY SUMMARY REPORT

BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE – ADVISORY COMMITTEE CHARTER

THE MYTHOLOGY AND MESSY REALITY OF NUCLEAR FUEL REPROCESSING

REPROCESSING NUCLEAR WASTE – PRESENTATION BY BRUCE BRESLOW, EXECUTIVE DIRECTOR, NEVADA AGENCY FOR NUCLEAR PROJECTS

THE QUESTION OF REPROCESSING WASTE AT YUCCA MOUNTAIN AND WHY IT IS A BAD IDEA

YUCCA MOUNTAIN – LESSONS TO BE LEARNED AND A STRATEGY FOR THE FUTURE: STATE OF NEVADA PRESENTATION TO THE BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

D R A F T

Technical and Scientific Reasons Why Disposal of Radioactive Waste and Spent Nuclear Fuel at Yucca Mountain Is Unacceptable and Not Adequately Protective of Human Health and Safety

The need to achieve safe disposal of high-level radioactive wastes and spent nuclear fuel is a matter that has to be addressed by any country with a significant nuclear program. Worldwide, there is broad agreement that deep geological disposal is the preferred option, with the intent being that the geological environment will provide long-term protection of the waste packages from degradation, and will limit the transport of radionuclides to the human environment in the event of container failure. Thus, for example, in Sweden and Finland, the proposal is to dispose of spent fuel in copper canisters in a geological environment in which significant degradation of the packages would not be expected on a timescale of one million years or longer.

In contrast, the geological environment at Yucca Mountain provides essentially no protection of the waste packages against degradation and would do little to limit the transport of radionuclides from those packages once they had degraded. Thus, the DOE can only argue for the long-term safety of the proposed facility based on projection of the performance of complex engineered materials and structures over timescales longer than the total duration of human civilization. In contrast, the materials that they rely on have only been used for engineering purposes for, at most, a few decades. Furthermore, although resistant to degradation in some contexts, it has been demonstrated experimentally that these materials would not maintain their physical integrity in the environment that would be present in a repository at Yucca Mountain.

A fundamental problem with the proposed Yucca Mountain facility is that it is positioned above the water table in a location where corrosively aggressive infiltrating water would contact the waste containers. No other country is proposing to locate a repository above the water table, so the problems that arise are unique to the US program and are not being addressed by research and development activities elsewhere in the world. Safety analyses conducted by the DOE have shown that disposal of waste packages of the proposed design at Yucca Mountain would give rise to radiation doses to members of the local population far in excess of the Federal Standard set by the Environmental Protection Agency to protect public health. Furthermore, this violation of the Standard is projected to occur within a few hundred years of repository closure.

Faced with this fundamental obstacle to demonstrating the safety of the proposed repository, the DOE License Application introduces an additional design feature. It posits the existence of titanium alloy ‘drip shields’, one 5-ton drip shield over each of the 11,500 waste packages, to ward off the corrosion-promoting water. However, these extremely expensive drip shields are not part of the current waste installation plan, but are intended to be installed by a yet-to-be-designed, remote-controlled robotic mechanism about one hundred years after the wastes have been emplaced. Taking account of the high temperature (above boiling point), high radiation, physically degraded environment that would exist at that time, it seems unlikely that

efficient and comprehensive installation of the drip shields could be achieved, even if the political will to undertake that installation could be relied upon. It is not acceptable to base public safety on such a technically risky and politically uncertain proposition.

The problems in developing a safety case for Yucca Mountain arise essentially from selection of an inappropriate site and an invalid disposal concept. Although located in a desert region, the unsaturated rock at Yucca Mountain contains large quantities of water that can percolate rapidly downward to the saturated zone, where it is then carried away horizontally toward the residential and agricultural area of Amargosa Valley. The downward seeping water would enter the hot, oxidizing environment of the waste tunnels and there promote rapid waste package corrosion, waste dissolution and the migration of radionuclides to a major pristine aquifer and hence to Amargosa Valley, contaminating groundwater resources there to an unacceptable degree. No other country is considering a repository attaining temperatures as high as those proposed at Yucca Mountain. Nor are other proposed repositories located in unsaturated, oxidizing environments where reliance has to be placed entirely on the predicted performance of complex engineered materials and structures to achieve safety. Indeed, location of a repository in the conditions existing at Yucca Mountain is ruled out by generally accepted international standards. The United States, as a party to the 2001 *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* is obligated to conform to such standards, if this is reasonable.

Not only is the location of the proposed Yucca Mountain repository inconsistent with international standards, but those standards also include the requirement that the design should incorporate redundant barriers. That is, the overall performance of the geological disposal system should not be unduly dependent on a single barrier or function. This is usually called defense-in-depth and is a basic feature of nuclear power reactor safety as regulated by the NRC. Defense-in-depth does not exist in the proposed Yucca Mountain repository design, as compliance with Federal Safety Standards depends entirely on the installation and performance of the drip shields, neither of which can be assured at the time of licensing.

The foregoing general objections apply even if the results of calculations presented by the DOE in the Yucca Mountain License Application are accepted. However, the scientific and technical bases of these calculations are open to question. Three independent panels of NRC judges comprised of lawyers and scientists have determined that the License Application raises 300 significant safety and environmental issues that would have to be fully and satisfactorily resolved before any license could be issued. These issues include:

- The appropriate representation of future climate in the area;
- The selection of models to characterise water flow;
- The chemical composition of the water that would contact the drip shields (if installed) and waste packages;
- The corrosion resistance and failure mechanisms of drip shields and waste packages;
- The sorption of radionuclides to minerals in the rock;
- The behaviour of radionuclides in the biosphere.

Further issues relate to vulnerabilities of surface facilities to military aircraft crashes and the overall vulnerability of the site to future volcanic events.

The unprecedented number, scope and technical depth of the admitted contentions relating to these issues suggest that, taken together, they cannot reasonably be expected to be resolved in favor of the proposed repository. To date, some nine billion dollars have been expended in investigating the Yucca Mountain site and in developing a grossly inadequate licence application. To proceed with repository construction would result in the expenditure of several times as much over the next decade, but with a high likelihood that the resulting facility would then be found to be unacceptable for disposal of either spent fuel or high-level wastes.

DRAFT

THE 2010 STATE OF NEVADA YUCCA MOUNTAIN RISK STUDY SUMMARY REPORT

Prepared By
The Nevada Agency for Nuclear Projects

June 2010

THE 2010 STATE OF NEVADA
YUCCA MOUNTAIN RISK STUDY
SUMMARY REPORT
June 2010

Introduction

The following information was collected by means of a statewide telephone survey done between June 11th and 18th, 2010. The survey was conducted by the research firm of Steve Johnson & Associates based in Eugene, Oregon and affiliated with the University of Oregon.

From a randomly generated list of 12,232 telephone numbers, 500 completed interviews were obtained. The response rate for the survey was 30.56%, and the margin of error is plus or minus 4.38%.

Forty-six (46%) of respondents were male and 54% were female. Eighty-seven percent (87%) said they were registered voters. Of those 34.4% were Democrats; 33.4% Republicans; 12% were Independents; and 20.2% were affiliated with other parties, not registered, or declined to answer.

About fifteen percent (14.9%) of respondents were between 18 and 39 years of age; 29.8% were between 40 and 54 years of age; and 50.9% were 55 and older.

For additional information, contact:

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Summary of Key Findings

Public Sentiment For and Against Yucca Mountain

The survey found that, despite ongoing nuclear power industry promotional activities in Nevada, opposition to the program remains extremely high. Statewide, 63.4% of Nevadans oppose locating a high-level nuclear waste repository at Yucca Mountain and would vote against it if given the opportunity. Only 32.2% support the project.

Continued Opposition vs. Making a Deal

Nevadans also remain strongly opposed to the State abandoning the fight to stop the Yucca Mountain project. The survey asked people to respond to the following question:

> "Some people think Nevada should stop fighting the repository and instead try to make a deal with the federal government for benefits. Other people believe Yucca Mountain is a poor choice, and that state resistance should not be weakened or compromised by entering into a deal for benefits. Do you believe the state should stop its opposition and make a deal, or do you think the state should continue to do all it can to oppose the repository, even if that means turning down benefits that may be offered by the federal government."[1]

58.2% of the respondents favored continuing State opposition, even if that meant turning down benefits, while 35.6% favored making a deal.

The survey was specifically designed to assure that the question on whether to continue opposition or make a deal was not preceded by questions or information that would bias the response. The oppose or make a deal question was number two in the survey, right after the first question that asked whether a respondent would vote for or against Yucca Mountain if given the opportunity.

In order to obtain an indication of how recent events might have affected people's views on whether Nevada should try to make a deal or continue to oppose the project, the same question was included once more in the questionnaire - near the very end. When asked the question for the

[1] This question was carefully crafted by social scientists to avoid biasing respondents while framing the issue in a clear and concise manner.

second time, 61.4% favored continuing opposition and rejecting benefits, while 34.8% favored cutting a deal.

Somewhat surprisingly, given the amount of media attention that has been given to the Yucca Mountain issue over the past few months, less than half of the respondents (49.4%) were aware of DOE's decision to withdraw the Yucca Mountain license application, while 49% were not aware of it.

Actions the State Could Take to Stop the Project

Respondents were also asked whether they agreed or disagreed with various actions the State could take in its efforts to oppose the project.

Table 1

Ranking of public support for actions the State of Nevada can take in its efforts to stop the Yucca Mountain project (Questions 7 – 11):

	Type of Action	% Agree	% Disagree
#1	Stop waste shipments from coming into Nevada	59.0%	38.8%
#2	Deny DOE water permits for the project	53.8%	42.2%
#3	Lawsuits to stop the project	53.6%	43.6%
#4	Vigorously oppose DOE's license Application in the proceeding before the Nuclear Regulatory Commission	51.2%	41.8%
#5	Actions to stop other DOE activities at NTS in protest	47.6%	45.6%

As Table 1 shows, Nevadans strongly endorse the State taking action to stop waste shipments from coming into Nevada (59%). There is also support for denying DOE water permits needed for the project (almost 54%); the continued use of litigation as a way to stop the Yucca Mountain project (53.6%); and vigorous opposition to DOE's license application before the NRC (51.2%).

State actions aimed at halting other DOE activities at the Nevada Test Site in protest over Yucca Mountain were not viewed as favorably, with about 48% supportive and 46% opposed..

Risks from the Yucca Mountain Project

Respondents were asked to rank risks potentially associated with the Yucca Mountain project as being little or no risk, slight risk, moderate risk, or high risk. Table 2 summarizes results from these questions.

Table 2

Ranking of risks people associate with the Yucca Mountain project and related activities (Questions 12 – 18):

		High/Moderate Risk	Low/No Risk
#1	Rail and truck shipments of radioactive waste	75.8%	23.4%
#2	Radioactive contamination of the environment	69.8%	27.4%
#3	Losses to property values for homes and businesses located near shipping routes	69.4%	29.6%
#4	Adverse health effects	64.2%	34.6%
#5	Damage to Nevada's reputation as a place to vacation or live	56.8%	43.0%
#6	Loss of public revenues due to reduced numbers of visitors/tourists	54.0%	45.4%
#7	Economic damage to Nevada's major industries	51.8%	45.6%

Risks associated with the transport of spent nuclear fuel and high-level radioactive waste by rail and highway ranked first, with almost seventy-six percent (75.8%) of respondents considering such risks to be of moderate to high risk. Of those, almost 59% considered waste transportation to be in the high risk category.

Radioactive contamination of the air and water ranked second (almost 70%), followed by the risk of loss to property values along nuclear waste shipping routes (over 69%), the risk of adverse heath effects from the repository itself or from transportation operations (over 64%), the risk of damage to Nevada's reputation as a place to live or visit (almost 57%), the risk that public revenues would be lost due to decreased numbers of visitors and tourists (54%); and the risk of serious economic damage to Nevada's major tourism and gaming industries (almost 52%).

Economic Impacts of Yucca Mountain on Nevada

Respondents were asked their views on two opposing perspectives on the impact Yucca Mountain would have on the State's economic future:

> "Public discussion of the economic effects of Yucca Mountain presents two opposite views. One position says that Department of Energy employment and spending in Nevada will provide significant economic benefits to Nevada. The other position says that development of the repository and transportation of high-level radioactive waste through the state will compromise Nevada as a place to visit, move to, or invest in, leading to significant economic losses.
>
> Do you think the Yucca Mountain project will have a positive economic impact on Nevada or a negative economic impact on Nevada?"

Almost fifty-six percent (55.6%) said that the Yucca Mountain project will have a negative economic impact on the State, with 37.6% perceiving positive economic effects.

Trust in the Department of Energy

When asked whether DOE can be expected to live up to any benefits agreement the federal government might (hypothetically) make with Nevada, almost sixty percent (59.4%) indicated DOE cannot be trusted. Just 34.2% considered DOE trustworthy.

DOE's Decision to Withdraw the Yucca Mountain License Application

One somewhat surprising finding of the survey involved the level of public awareness of DOE's decision to withdraw the Yucca Mountain license application and abandon the project. Almost half of the respondents (49%) indicated that they had not heard of DOE's action while 49.4% were aware of it. Given the amount of media attention generated by this issue over the past 6 months, it was unexpected that such a large percent of the population would not have heard about the decision to terminate the Yucca Mountain project.

When asked if they supported or opposed DOE's decision to abandon Yucca, 59.8% indicated they supported abandonment while 36.8% opposed it.

Analyses and Correlations

Despite the challenging economic times the State is facing and strong pressure from pro-Yucca Mountain nuclear industry groups touting perceived economic windfalls for agreeing to go along with a Yucca Mountain nuclear waste repository, almost two-thirds of Nevadans remain opposed to the project, with almost sixty percent advocating continued opposition even if that meant turning down benefits. This finding seems to reflect the strength of opposition to the project among Nevadans and a continued strong aversion to federal efforts to bring nuclear waste to the state.

There are, however, significant differences in opposition or support for the project when results are analyzed in terms of gender and age.

One area of statistically significant difference is in the way men and women view the Yucca project. As in past surveys, gender differences are striking. Over 72% of women in the survey indicated they would vote against the project if given the opportunity, compared to 53% of men. While a clear majority of males oppose Yucca Mountain, this gender gap is something that permeates every question category, with significantly larger percentages of women indicating higher degrees of concern over risks and stronger levels of support for actions to oppose the project.

The other variable where significant differences are seen in the way the Yucca Mountain project is perceived is the age of respondents. While a clear majority in all age groups oppose the project, younger people (age 18 – 39) are most strongly opposed (almost 71%), followed by older individuals in the 55 and over category (63.7%). A significantly smaller percentage (54%) of people between the ages of 40 and 54 oppose the project.

ATTACHMENT I
2010 NEVADA STATE SURVEY
QUESTION-BY-QUESTION SURVEY RESULTS

Question 1:

The federal Department of Energy (DOE) wants to build the nation's first high-level radioactive waste repository at Yucca Mountain in southern Nevada. If given the opportunity to vote on this matter, would you vote for or against locating a nuclear waste repository at Yucca Mountain?

VOTE FOR	32.2%
VOTE AGAINST	63.4%
REFUSED/DON'T KNOW/NO ANSWER	4.4%

Question 2:

Some people think Nevada should stop fighting the repository and instead try to make a deal with the federal government for benefits. Other people believe Yucca Mountain is a poor choice, and that state resistance should not be weakened or compromised by entering into a deal for benefits. Do you believe the state should stop its opposition and make a deal, or do you think the state should continue to do all it can to oppose the repository, even if that means turning down benefits that may be offered by the federal government.

MAKE A DEAL	35.6%
CONTINUE OPPOSITION	58.2%
REFUSED/DON'T KNOW/NO ANSWER	6.2%

Question 3:

Public discussion of the economic effects of Yucca Mountain presents to opposite views. One position says that DOE employment and spending in Nevada will provide significant economic benefits to Nevada. The other position says that development of the repository and transportation of high-level radioactive wastes through the state will stigmatize Nevada as a place to visit, move to, or invest in, leading to significant economic losses. Do you think the Yucca Mountain project will have:

POSITIVE	37.6%
NEGATIVE	55.6%
REFUSED/DON'T KNOW/NO ANSWER	6.8%

Question 4:

Supporters of the Yucca Mountain program say that the Department of Energy (DOE) can be trusted to live up to any benefits agreement the federal government would make with Nevada. Do you strongly agree, agree, disagree, or strongly disagree with this claim?

AGREE	34.2%
DISAGREE	59.4%
REFUSED/DON'T KNOW/NO ANSWER	6.4%

Question 5:

There are a number of actions that the State of Nevada could take in its efforts to stop the Yucca Mountain project. Please tell me if you would strongly agree, agree, disagree or strongly disagree with the following actions.

The first one is, vigorously opposing the Department of Energy's license application in the proceeding before the U.S. Nuclear Regulatory Commission. Would you strongly agree, agree, disagree or strongly disagree with this step?

AGREE	51.2%
DISAGREE	41.8%
REFUSED/DON'T KNOW/NO ANSWER	7.0%

Question 6:

Filing law suits in the courts to stop the project. Would you strongly agree, agree, disagree or strongly disagree with this step?

AGREE	53.6%
DISAGREE	43.6%
REFUSED/DON'T KNOW/NO ANSWER	2.8%

Question 7:

Denying the Department of Energy (DOE) water permits it needs for the project

AGREE	53.8%
DISAGREE	42.2%
REFUSED/DON'T KNOW/NO ANSWER	4.0%

Question 8:

Taking action to stop DOE's other activities at the NTS in protest

AGREE	47.6%
DISAGREE	45.6%
REFUSED/DON'T KNOW/NO ANSWER	6.8%

Question 9:

Stopping shipments of spent nuclear fuel or high-level nuclear waste from crossing into the state.[2]

[2] The 2004 survey used the following wording: "Using the Highway Patrol to stop shipments of high-level nuclear waste in Nevada."

AGREE	59.0%
DISAGREE	38.8%
REFUSED/DON'T KNOW	2.2%

Question 10:

The federal government and the State of Nevada have identified several risks presented by the Yucca Mountain repository program. I am going to read a short list and I would like you to tell me if you, personally, think these are items with little or no risk, slight risk, moderate risk, or high risk. The first one is, rail and truck shipments of up to 100,000 casks of high-level radioactive wastes across the country to Nevada. Do you think this item is of little or no risk, slight risk, moderate risk, or high risk?

LITTLE OR NO RISK	12.6%
SLIGHT RISK	10.8%
MODERATE RISK	17.2%
HIGH RISK	58.6%
REFUSED/DON'T KNOW/NO ANSWER	0.8%

Question 11:

Risk of radioactive contamination by radioactive emissions into the air and water over the next 10,000 years

LITTLE OR NO RISK	16.4%
SLIGHT RISK	11.0%
MODERATE RISK	13.6%
HIGH RISK	56.2%
REFUSED/DON'T KNOW/NO ANSWER	2.8%

Question 12:

Economic damage to major industries such as gaming and conventions because people avoid Nevada as the "Nuclear Dump State"

LITTLE OR NO RISK	35.6%
SLIGHT RISK	10.0%
MODERATE RISK	16.4%
HIGH RISK	35.4%
REFUSED/DON'T KNOW/NO ANSWER	2.6%

Question 13:

Damage to Nevada's reputation as a place to vacation or live

LITTLE OR NO RISK	33.2%
SLIGHT RISK	9.8%
MODERATE RISK	16.8%
HIGH RISK	40.0%
REFUSED/DON'T KNOW/NO ANSWER	0.2%

Question 14:

Risk of loss of public revenues because of a reduced number of visitors and tourists

LITTLE OR NO RISK	34.0%
SLIGHT RISK	11.4%
MODERATE RISK	15.2%
HIGH RISK	38.8%
REFUSED/DON'T KNOW/NO ANSWER	0.6%

Question 15:

Adverse health effects for Nevada residents from radioactive transportation and operations of a repository

LITTLE OR NO RISK	23.4%
SLIGHT RISK	11.2%
MODERATE RISK	14.6%
HIGH RISK	49.6%
REFUSED/DON'T KNOW/NO ANSWER	1.2%

Question 16:

Losses to property value for homes and businesses located near highways and railroads used for shipping nuclear waste to Yucca Mountain

LITTLE OR NO RISK	20.8%
SLIGHT RISK	8.8%
MODERATE RISK	16.4%
HIGH RISK	53.0%
REFUSED/DON'T KNOW/NO ANSWER	1.0%

Question 17:

Taking into account everything you know about the Yucca Mountain project, do you now think that Nevada should stop fighting the repository and instead try to make a deal with the federal government for

benefits? Or do you think that Yucca Mountain is a poor choice, and that state resistance should not be weakened or compromised by entering into a deal for benefits?

MAKE A DEAL	34.8%
CONTINUE OPPOSITION	61.4%
REFUSED/DON'T KNOW/NO ANSWER	3.8%

Question 18:

The election of a new Administration in 2008 that took office in 2009 had DOE conduct a review of the Yucca Mountain project. As a result of that review, DOE filed a request to withdraw the license application for Yucca Mountain that had been submitted to the Nuclear Regulatory Commission. This action would abandon Yucca Mountain as the site of a High-Level Radioactive Waste Repository.

Have you heard of this action at the federal level?

YES	49.4%
NO	49.0%
REFUSED/DON'T KNOW/NO ANSWER	1.6%

Question 19:

Do you support or oppose the abandonment of the repository program at Yucca Mountain?

SUPPORT ABANDONMENT	59.8%
OPPOSE ABANDONMENT	36.8%
REFUSED/DON'T KNOW/NO ANSWER	3.4%

Question 20

Do you think the Yucca Mountain repository will eventually be abandoned as a poor choice, or that DOE will build at Yucca Mountain?

YUCCA WILL BE ABANDONED	39.8%
DOE WILL BUILD AT YUCCA	46.2%
REFUSED/DON'T KNOW/NO ANSWER	14.0%

Department of Energy
Washington, DC 20585

Blue Ribbon Commission on America's Nuclear Future
U.S. Department of Energy

Advisory Committee Charter

1. **Committee's Official Designation.** Blue Ribbon Commission on America's Nuclear Future (the Commission).

2. **Authority.** The Commission is being established in accordance with the provisions of the Federal Advisory Committee Act (FACA), as amended, 5 U.S.C. App. 2, and as directed by the President's Memorandum for the Secretary of Energy dated January 20, 2010: Blue Ribbon Commission on America's Nuclear Future. This charter establishes the Commission under the authority of the U.S. Department of Energy (DOE).

3. **Objectives and Scope of Activities.** The Secretary of Energy, acting at the direction of the President, is establishing the Commission to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high-level waste, and materials derived from nuclear activities. Specifically, the Commission will provide advice, evaluate alternatives, and make recommendations for a new plan to address these issues, including:

   a) Evaluation of existing fuel cycle technologies and R&D programs. Criteria for evaluation should include cost, safety, resource utilization and sustainability, and the promotion of nuclear nonproliferation and counter-terrorism goals.

   b) Options for safe storage of used nuclear fuel while final disposition pathways are selected and deployed;

   c) Options for permanent disposal of used fuel and/or high-level nuclear waste, including deep geological disposal;

   d) Options to make legal and commercial arrangements for the management of used nuclear fuel and nuclear waste in a manner that takes the current and potential full fuel cycles into account;

   e) Options for decision-making processes for management and disposal that are flexible, adaptive, and responsive;

   f) Options to ensure that decisions on management of used nuclear fuel and nuclear waste are open and transparent, with broad participation;

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g) The possible need for additional legislation or amendments to existing laws, including the Nuclear Waste Policy Act of 1982, as amended; and

h) Any such additional matters as the Secretary determines to be appropriate for consideration.

The Commission will produce a draft report to the Secretary and a final report within the time frames contained in paragraph 4.

4. **Description of Duties.** The duties of the Commission are solely advisory and are as stated in Paragraph 3 above.

   A draft report shall be submitted within 18 months of the date of the Presidential memorandum directing establishment of this Commission; a final report shall be submitted within 24 months of the date of that memorandum. The reports shall include:

   a) Consideration of a wide range of technological and policy alternatives, and should analyze the scientific, environmental, budgetary, financial, and management issues, among others, surrounding each alternative it considers. The reports will also include a set of recommendations regarding policy and management, and any advisable changes in law.

   b) Recommendations on the fees currently being charged to nuclear energy ratepayers and the recommended disposition of the available balances consistent with the recommendations of the Commission regarding the management of used nuclear fuel; and

   c) Such other matters as the Secretary determines to be appropriate.

5. **Official to Whom the Committee Reports.** The Commission reports to the Secretary of Energy.

6. **Agency Responsible for Providing the Necessary Support.** DOE will be responsible for financial and administrative support. Within DOE, this support will be provided by the Office of the Assistant Secretary for Nuclear Energy or other Departmental element as required. The Commission will draw on the expertise of other federal agencies as appropriate.

7. **Estimated Annual Operating Cost and Staff Years.** The estimated annual operating cost of direct support to, including travel of, the Commission and its subcommittees is $5,000,000 and requires approximately 8.0 full-time employees.

8. **Designated Federal Officer.** A full-time DOE employee, appointed in accordance with agency procedures, will serve as the Designated Federal Officer

(DFO). The DFO will approve or call all of the Commission and subcommittee meetings, approve all meeting agendas, attend all Commission and subcommittee meetings, adjourn any meeting when the DFO determines adjournment to be in the public interest. Subcommittee directors who are full-time Department of Energy employees, as appointed by the DFO, may serve as DFOs for subcommittee meetings.

9. **Estimated Number and Frequency of Meetings.** The Commission is expected to meet as frequently as needed and approved by the DFO, but not less than twice a year.

   The Commission will hold open meetings unless the Secretary of Energy, or his designee, determines that a meeting or a portion of a meeting may be closed to the public as permitted by law. Interested persons may attend meetings of, and file comments with, the Commission, and, within time constraints and Commission procedures, may appear before the Commission.

   Members of the Commission serve without compensation. However, each appointed non-Federal member may be reimbursed for per diem and travel expenses incurred while attending Commission meetings in accordance with the Federal Travel Regulations.

10. **Duration and Termination.** The Commission is subject to biennial review and will terminate 24 months from the date of the Presidential memorandum discussed above, unless, prior to that time, the charter is renewed in accordance with Section 14 of the FACA.

11. **Membership and Designation.** Commission members shall be experts in their respective fields and appointed as special Government employees based on their knowledge and expertise of the topics expected to be addressed by the Commission, or representatives of entities including, among others, research facilities, academic and policy-centered institutions, industry, labor organizations, environmental organizations, and others, should the Commission's task require such representation. Members shall be appointed by the Secretary of Energy. The approximate number of Commission members will be 15 persons. The Chair or Co-Chairs shall be appointed by the Secretary of Energy.

12. **Subcommittees.**

    a) To facilitate functioning of the Commission, both standing and ad hoc subcommittees may be formed.

    b) The objectives of the subcommittees are to undertake fact-finding and analysis on specific topics and to provide appropriate information and recommendations to the Commission.

c) The Secretary or his designee, in consultation with the Chair or Co-Chairs, will appoint members of subcommittees. Members from outside the Commission may be appointed to any subcommittee to assure the expertise necessary to conduct subcommittee business.

d) The Secretary or his designee, in consultation with the Chair or co-Chairs will appoint Subcommittees.

e) The DOE Committee Management Officer (CMO) will be notified upon establishment of each subcommittee.

13. Recordkeeping. The records of the Commission and any subcommittee shall be handled in accordance with General Records Schedule 26, Item 2 and approved agency records disposition schedule. These records shall be available for public inspection and copying, subject to the Freedom of Information Act, 5 U.S.C. 552.

14. Filing Date.

Date filed with Congress: _____March 1, 2010_____

Signed

_____

Carol A. Matthews
Committee Management Officer

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THE MYTHOLOGY AND MESSY REALITY OF NUCLEAR FUEL REPROCESSING

Arjun Makhijani, Ph.D.

April 8, 2010

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I would like to thank Professor Frank von Hippel of Princeton University for his review of a draft of this report and the many useful comments he made on very short notice. His comments have enabled many improvements and refinements. Of course, as the report's author, I alone am responsible for any errors that remain and, more generally, for its contents, findings, and recommendations.

As is normal at IEER, Lois Chalmers, our librarian, was the bibliographic anchor of this work. She tirelessly checks sources, finds reference materials, and proof-reads each time changes are made. Annie Makhijani did a good bit of the research on the French reprocessing program and also prepared the Sankey diagram showing resource and waste flows in a thermal reactor system with reprocessing and re-enrichment. I am very grateful to have them as colleagues and I deeply appreciate their work.

This report was funded mainly by a generous gift to IEER by a donor who wishes to remain anonymous. IEER's work on nuclear non-proliferation, disarmament, and energy issues is also funded by grants from the Ford Foundation, the Colombe Foundation, the New-Land Foundation, the Town Creek Foundation, Livingry Foundation, the Steward R. Mott Charitable Trust, Elmo Foundation, and the Kindle Project Fund. IEER staff are deeply appreciative of the trust in our work and the commitment to public interest work, to environmental and health protection, to peace, and to nuclear non-proliferation and nuclear weapons elimination that these grants represent.

Arjun Makhijani
April 2010

Findings and recommendations

> You had uranium in the rocks, in principle an inexhaustible source of energy – enough to keep you going for hundreds of millions of years. I got very, very excited about that because here was an embodiment of a way to save mankind. I guess I acquired a little bit of the same spirit as the Ayatollah [Khomeini] has at the moment.
>
> Alvin Weinberg, first director of Oak Ridge National Laboratory, 1981[1]

The messianic pronouncements of the 1950s about nuclear power were, in large part, based on the notion of an "inexhaustible" energy source. This required the conversion of uranium-238, which constitutes about 99.3 percent of natural uranium and is not a nuclear reactor fuel, into plutonium in special reactors called "breeder reactors"; it also needed facilities to separate that plutonium from highly radioactive waste and unused uranium (called "reprocessing"). In 1954 the Chairman of the Atomic Energy Commission, Lewis Strauss, proposed that nuclear energy would one day be "too cheap to meter."[2]

In recent years, a French fever has gripped the promoters of nuclear power in the United States. Praise of its management of spent fuel by reprocessing, including its use of the extracted plutonium as fuel in its nuclear power reactors, is routine. For instance, Bill Magwood, who was appointed to the Nuclear Regulatory Commission by President Obama, wrote an open "memorandum" to him in mid-January 2009, with Mark Ribbing of the Progressive Policy Institute:

> While looking to France for inspiration may or may not play well with domestic audiences, it is one of the first places to look for ideas on how to handle nuclear waste. Actually, the French…do not really think of it as waste….
>
> …After a three-year cooling-down period, 96 percent or 97 percent of that material is potentially reusable uranium or plutonium; only the remaining 3 percent or 4 percent is genuinely useless "waste."
>
> France "reprocesses" that leftover uranium and plutonium into useable energy….[3]

Commissioner Magwood and Mark Ribbing acknowledge proliferation problems with the existing French approach but believe they will be overcome by new technology; in addition, new ways would be found to "to break waste down into stable, non-radioactive materials using 'fast reactors.'"[4]

This has become a new mantra of nuclear waste management. Spent fuel is a treasure-trove of energy. This report shows that for existing spent fuel – the main waste problem facing the United States – the slogan belongs in the same realm of economic claims for nuclear energy that would be "too cheap to meter."

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[1] As quoted in Ford 1982 p. 25.

[2] For a history of early assessments and pronouncements about nuclear energy, including the quote and context of "too cheap to meter" see Makhijani and Saleska 1999.

[3] Magwood and Ribbing 2009

[4] Magwood and Ribbing 2009. "Fast reactors" refers to reactors that sustain the chain reactor with "fast" (high energy) neutrons.

Findings

1. *The reasons developing reprocessing for commercial nuclear power have been proved to be wrong.* In the early years of nuclear technology it was thought that:

- Uranium would be scarce and expensive,
- Sodium-cooled breeders could be developed with reasonable speed and cost.
- The proliferation problems related to reprocessing could be overcome.
- Costs of breeder reactors plus reprocessing would be modest.

None of these assumptions have been borne out. Neither breeder reactors nor reprocessing are commercial despite worldwide expenditures on the order of $200 billion so far.

2. *Reprocessing as done in France does not solve the waste problem.* When high-level waste and Greater than Class C waste are considered together, the volume of waste to be disposed of in a repository is greater by about six times compared to the no-reprocessing approach that is current U.S. policy on a life-cycle basis. Low-level waste and waste shipments are also increased several fold by reprocessing. These are Department of Energy estimates comparing present U.S. once-through policy with the French "recycling" system using thermal reactors.

3. *Reprocessing involves a great deal of additional cost compared to once-through fuel uranium use.* France spends about two cents per kilowatt-hour more for electricity generated from reprocessed plutonium compared to that generated from fresh uranium fuel.

4. *Storage of liquid high-level wastes arising from present-day reprocessing technology creates a risk of catastrophic releases of radioactivity.* For instance, the Norwegian Radiation Protection Authority has estimated that a severe accident at the liquid waste storage facility in Sellafield, Britain, could result in cesium-137 contamination between 10 percent and 5,000 percent of that created in Norway by the 1986 Chernobyl nuclear reactor accident, which is the worst commercial accident to date, by far. A catastrophic release of radioactivity from a military high-level waste tank occurred in the Soviet Union in 1957.

5. *France needs a geologic repository and opposition to one has been intense there.* The French appear to dislike nuclear waste in their backyards as much as people in the United States.

6. *Using more than one percent of the uranium resource in a light water reactor system is technically impossible even with reprocessing and re-enrichment.* In light water reactor systems, almost all the uranium resource winds up as depleted uranium or in spent fuel. Even with repeated reprocessing and re-enrichment, use of the natural uranium resource cannot be increased to more than one percent in such a system. A corollary is that the use of 90 to 95 percent of the uranium resource in the spent fuel is impossible in a light water

reactor system even with reprocessing. These are technical constraints that go with the system and also apply to France's system.

7. *There has been essentially no learning curve for the sodium-cooled fast breeder reactor.* In fact, the two most recent large scale demonstration reactors, Superphénix in France and Monju in Japan, have been economic failures. Yet, to make significant use of the uranium resource, breeder reactors are required. They are not commercial today despite global expenditures on the order of $100 billion over six decades. They are unlikely to be commercial in the near future. For instance, Japan's estimated date for commercialization of the sodium-cooled fast breeder is 2050.

8. *Proliferation risks are part of any reprocessing approach, including advanced ones like electrometallurgical processing, which is slated to be considered by the Blue Ribbon Commission.* While electrometallurgical processing reduces some proliferation risks relative to separation of pure plutonium, it also increases them in other ways. For instance, it is less difficult to conceal such a plant than with the present PUREX technology. A study by authors from a number of DOE laboratories, expressing their own conclusions, found that "only a modest improvement in reducing proliferation risk over existing PUREX technologies and these modest improvements apply primarily for non-state actors."[5]

9. *To propose, as some have done, that most of the uranium resource value in existing spent fuel could be used is in the realm of economic mythology, like the "too cheap to meter" slogan of the 1950s.* Reprocessing plus breeder reactors are much more expensive than light water reactors today, which in turn cost more than wind-generated electricity. To use most of the uranium resource, breeder reactors would have to move to the center of U.S. electricity generation. It cannot be done using light water reactors. Even a single penny in excess generation cost per kilowatt-hour in a breeder reactor-reprocessing system would lead to an added $8 trillion in costs if essentially all the uranium, including the uranium-238, and the plutonium in the 100,000 metric tons of spent fuel that existing U.S. reactors have generated or will generate during their licensed lifetimes is to be used as fuel. At present, the economic hurdle is far greater than a penny per kWh. Further, it would take hundreds of years to accomplish the task, involving the separation of tens of thousands of nuclear bombs worth of fissile material every year. The inspection, verification, and materials accounting problems of the adoption of the approach globally would present problems that are far greater than any concerns to date, which have been significant. It will also require storage of a significant part of the spent fuel for very long periods – likely in the hundreds of years. On-site storage is the most secure management option available today. But extending on-site storage to hundreds of years will create its own economic and security concerns. This is the principal reason that direct deep geologic disposal of spent fuel should be developed.

10. *No reprocessing program can obviate the need for a deep geologic repository.* Even complete fissioning of all actinides – an unrealistic proposition – will leave behind large amounts of very long-lived fission and activation products like iodine-129, cesium-135,

[5] Bari et al. 2009

and chlorine-36 that will pose risks far into the future much beyond the 24,100-year half-life of plutonium-239.

Recommendations

Our main recommendations for the Blue Ribbon Commission on America's Nuclear Future appointed by Energy Secretary Steven Chu are as follows:

1. Spent fuel from existing reactors should be slated for direct deep geologic disposal without reprocessing of any kind; a suitable path for a scientifically sound program should be set forth.
2. In the interim, spent fuel should be stored on site as safely as possible – in low density configurations while in pools and in hardened storage when moved to dry casks.

Our other recommendations for the Commission are:

1. Breeder reactors and reprocessing are not commercial after six decades of development of sodium-cooled breeder reactors, and enormous expenditures. Given the long time frame for commercialization estimated even by some promoters, the proliferation risks, and the efforts already made, it does not appear to be a good investment to spend more R&D money in that direction. Rather energy supply R&D resources should be focused on development and deployment of renewable energy technologies and energy efficiency.
2. The Commission should request the French company AREVA and/or the French government to supply it with data on the present use of the natural uranium resource purchased for French nuclear reactors, including, specifically, the increases in fission fraction that have actually been achieved by reprocessing and recycle.
3. The Commission should also request official data on Greater than Class C waste equivalent expected to be generated on a life-cycle basis in France, and the total volumes and heat generation of packaged waste expected to be disposed of in a deep geologic repository, including estimates of decommissioning waste and direct disposal of MOX spent fuel.
4. The Commission should make the same requests regarding the British reprocessing program.
5. The Commission should investigate the public support or lack thereof for repository programs in France and Britain, the countries with the longest and most extensive history of commercial spent fuel reprocessing.
6. Official analyses of the mechanisms, probability, and consequences of large accidental releases of radioactivity to the atmosphere from liquid high-level waste storage in tanks should be requested from the French and British governments.

Official data from Britain and France would enable the Commission to do its own analysis of issues related to reprocessing spent fuel from burner reactors and help put the public discussion in the United States on a sounder scientific footing.

A. Introduction

Reprocessing is a technology for separating fissile materials – materials that can sustain a chain reaction[6] – from a more complex mixture created in a nuclear reactor so that they can be used either in nuclear weapons or in nuclear power reactors. It was initially developed during the World War II Manhattan Project for obtaining the plutonium-239 to make the bomb that was used on Nagasaki on August 9, 1945. This report deals with proposals to use reprocessing as a technology to manage nuclear spent fuel from commercial nuclear power reactors and potentially also to use some of the recovered materials, including plutonium-239, as fuel.

There is only one naturally-occurring fissile material – uranium-235.[7] It is only about 0.7 percent of natural uranium by weight, which also contains two other uranium isotopes: uranium-238 (just under 99.3 percent) and a trace of uranium-234 (about fifty parts per million). Neither uranium-234 nor uranium-238 is fissile. So, in effect, only about 0.7 percent of natural uranium consists of a material that can sustain a chain reaction and be used as a fuel in nuclear reactors.

However, it is possible to make new fissile materials by transmutation in nuclear reactors. Specifically, uranium-238, when irradiated with neutrons, transmutes into plutonium-239,[8] which is fissile. Since neutrons are emitted in the course of a chain reaction in a reactor (and in fact are needed to keep the chain reaction going), the conditions exist in a nuclear reactor for creating new fissile materials. Hence a reactor can create *new fissile material for bombs or for reactor fuel from a non-fuel radionuclide like uranium-238, at the same time as* the reactor is consuming nuclear fissile material and producing nuclear energy. Reactors that use more fissile material than they create are called "burner reactors," while those that make more fissile material than they use are called "breeder reactors." The possibility for "breeding" more fuel than was consumed in the course of energy generation engendered a passionate hope among many nuclear engineers and physicists of an energy source that would last essentially forever, given the abundance of uranium-238 compared to uranium-235. Because of this potential, Alvin Weinberg, the first director of Oak Ridge National Laboratory, called it a "magical" energy source.[9] Materials that are not fissile but can be made into fissile materials by irradiation with neutrons are called "fertile" materials. The main fertile materials that occur in nature are uranium-238 and thorium-232.[10]

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[6] Technically, a fissile material sustains a chain reaction with very-low or zero energy neutrons. A chain reaction occurs when a fission of a nucleus of an atom produces sufficient neutrons to trigger another fission and so on in a self-sustaining manner.

[7] There are extremely small quantities of transuranic fissile materials created in nature (due to spontaneous fission of uranium-238 in one out of two million disintegrations). However, the concentrations and quantities are so tiny that they are of no practical interest for nuclear energy for power or weapons.

[8] The nuclear reactions for the transmutation are as follows:
uranium-238 + neutron → uranium-239 → neptunium-239 + electron → plutonium-239 + electron.
For historical reasons, electrons emitted from the nucleus are called "beta particles."

[9] Weinberg 1972 p.33

[10] The fissile material created from thorium-232 in a nuclear reactor would be uranium-233 thus:
thorium-232 + neutron → thorium-233 → protactinium-233 + electron → uranium-233 + electron. Thorium fuel cycles are briefly considered in this report, which is mainly about reprocessing existing commercial spent fuel. Electrons emitted in the process of nuclear transformations are called "beta particles."

Commercial power reactors today do make plutonium from uranium-238 but they produce much less fuel that they consume. In other words, the breeding ratio – fuel created to fuel used – is less than one. In a breeder reactor, the breeding ratio would be more than one.

Reprocessing is needed in this scheme to separate the plutonium created in nuclear reactors from the remaining uranium isotopes, fission products, which are the radioactive fragments created in the process of liberating energy from the splitting of the nuclei of uranium-235 (or plutonium-239), and traces of other radionuclides, including other heavy radionuclides also created in the process of reactor operation. Chemical separation is at the center of current reprocessing technology. In the most common process, for instance the one used at Savannah River Site, called the PUREX process (for Plutonium URanium EXtraction), nitric acid is used to dissolve the mixture of radionuclides in the spent fuel. Solvents are then used in successive separation steps, first to separate fission products and some other trace radionuclides from uranium and plutonium and then uranium and plutonium from each other. Trace radionuclides are also generally separated from the uranium and plutonium streams. A schematic of this process is shown in Figure 1.

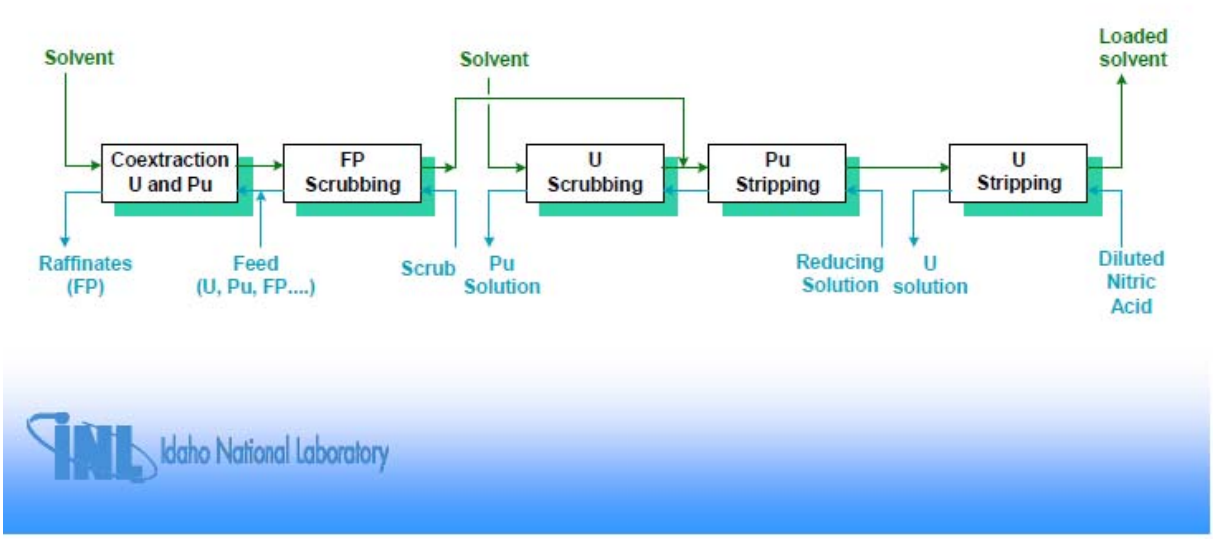

Figure 1: Schematic of the main separations process of PUREX reprocessing technology
Source: Todd 2009 Slide 22
Note: FP = fission products; U = uranium; Pu = plutonium.

1. Initial rationale for reprocessing and breeder reactors

In the context of nuclear power, reprocessing and breeder reactors first found great favor among physicists and nuclear engineers because uranium was thought to be a very scarce resource, with most of it being unusable as a fuel directly. The combination of these two technologies would, greatly increase the utilization of the uranium resource by converting non-fuel uranium-238 into plutonium-239. The favored reactor to do this is a "sodium-cooled fast breeder reactor," so called because it uses fast (energetic) neutrons to sustain the chain reaction and liquid sodium for cooling the reactor and carrying away the heat created by nuclear fission. The reason for favoring this type of reactor was its high theoretical breeding ratio, which, in principle, would

allow a relatively rapid increase in the amount of new fuel, and hence be an efficient breeder reactor design.

There was nothing wrong with the physics underlying the rationale for breeder reactors. But the success of the scheme depended on key technical, economic, and security assumptions, which have been proved wrong, as has been pointed out in a February 2010 report by the International Panel on Fissile Materials which surveyed breeder reactors programs country-by-country:

> The rationale for pursuing breeder reactors — sometimes explicit and sometimes implicit — was based on the following key assumptions:
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> 1. Uranium is scarce and high-grade deposits would quickly become depleted if fission power were deployed on a large scale;
> 2. Breeder reactors would quickly become economically competitive with the light-water reactors that dominate nuclear power today;
> 3. Breeder reactors could be as safe and reliable as light-water reactors; and,
> 4. The proliferation risks posed by breeders and their "closed" fuel cycle, in which plutonium would be recycled, could be managed.
>
> Each of these assumptions has proven to be wrong.[11]

An earlier study by IEER also arrived at essentially the same conclusions.[12] Overall, uranium remained cheap despite speculative ups and downs along the way; reprocessing turned out to be expensive relative to making reactor fuel from freshly mined uranium; sodium-cooled breeders proved too difficult to commercialize; and proliferation problems associated with non-military reprocessing became a central concern after the Indian nuclear test in 1974. The Indian nuclear test was the main motivation that led the United States to forgo commercial reprocessing in the mid-1970s. By that time, reprocessing was also not as commercially promising as it had been in the 1950s. Further, the West Valley reprocessing plant near Buffalo, New York, operated only for six years before it was permanently shut down in 1972.[13] We will explore these issues in more detail in this report.

It is worth noting at the outset that reprocessing and breeder reactors were *not* proposed as a solution to the problem of nuclear waste, which has so far turned out to be intractable for a host of technical, environmental, and political reasons. Reprocessing was also not proposed as an essential accompaniment to burner reactors, like the light water reactors, to increase the use of the uranium resource because its value in that regard is marginal, as we will see.

It is only recently, with the failure of the Yucca Mountain program to provide a timely repository – or indeed, any repository at all, it now appears[14] – that reprocessing is now being promoted as a

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[11] IPFM 2010 p. 5

[12] For an analysis of the failure of the breeder-reactor-reprocessing dream to develop an essentially inexhaustible energy source, see Makhijani 2001.

[13] It became a multi-billion dollar waste management and remediation nightmare for the State of New York and the federal government. After nearly four decades, remediation is far from complete.

[14] The Obama Administration has asked Congress to cut off funds for further site characterization on the grounds that the site is unsuitable. (Vogel 2009). The Obama Administration has also decided to withdraw the license

"solution" to the problem of mounting quantities of spent fuel at more than five dozen commercial nuclear reactor sites in the United States. In this context, it is often called "recycling." It is now explicitly being promoted as a means for greatly increasing the use of the uranium resource contained in the spent fuel. This line of argument was presented succinctly in an op-ed by William H. Miller, a professor of nuclear engineering with the University of Missouri's Nuclear Science and Engineering Institute, promoting reprocessing as a solution for the nuclear spent fuel ("used fuel") problem is typical:[15]

1. "[U]sed nuclear fuel contain[s] large quantities of valuable nuclear materials that can be recycled for further use in producing electricity…
2. "[S]queezing more energy out of used fuel would be good for the nation's economy and environment."
3. Over 95 percent of spent fuel (or used fuel or irradiated fuel) can be "recycled" for recovering the energy in it.
4. The balance of the waste, "less than 5 percent" of the total, would "decay away in a few centuries."
5. Reprocessing would make use of the uranium and plutonium resources in the spent fuel to reduce greenhouse gas emissions.
6. "[R]ecycling is a proven technology because at least a dozen other countries with nuclear power programs pursue it. France, in particular, has made efficient use of recycling and produces 80 percent of its electricity from nuclear power."
7. Proliferation is not an issue:

   > "President Jimmy Carter banned the use of nuclear recycling on the grounds it could lead to the proliferation of nuclear weapons.
   > It doesn't, and other countries know better. France and Great Britain recycle used fuel, and no plutonium has ever been diverted from French or British recycling facilities for weapons production."

Taken together, these propositions about reprocessing imply that France has found an economical and technical solution to all but about five percent of the waste problem by "recycling" 95 percent of spent fuel (see the quote in point number 6 above and point number 3 together). Professor Miller also implies that a nuclear waste repository may not be needed at all, since the remaining waste would "decay away in a few centuries" (point 4 above). This means that it could be stored and guarded until it becomes harmless, since we know of human institutions that have lasted more than a few hundred years. A further implication is that the United States is somehow stuck in a Jimmy-Carter time warp and failed to notice the great progress that the French and British have made in "recycling" used nuclear fuel since his presidency.

Others have expressed similar opinions, including Bill Magwood,[16] who headed the civilian nuclear energy development program in the Department of Energy for seven years and has been

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application for Yucca Mountain "with prejudice," which means that it "does not intend ever to refile" the application. (DOE 2010)

[15] Miller 2009 p. D3. List numbers supplied by IEER.

[16] Magwood and Ribbing 2009. A part of the article states: "Let's say you were to put a batch of nuclear fuel into a reactor. After a three-year cooling-down period, 96 percent or 97 percent of that material is potentially reusable

appointed a Commissioner of the Nuclear Regulatory Commission.[17] However, it should be noted that Commissioner Magwood was more careful than Professor Miller about proliferation issues related to PUREX reprocessing, which is the technology used in France.

As we shall see, conclusions such as those put forth by Professor Miller, while typical, do not hold up to the facts. The French have not solved the waste problem. Indeed, reprocessing has not and cannot solve the problem of nuclear waste in the sense implied above – that all but a few percent of the used fuel can be "recycled" efficiently and the remaining problem could be solved by storage for a few hundred years. Nor have the proliferation, cost, and technology problems associated with the so-called "recycling" been solved. Finally, converting most or all of the uranium-238 into fuel for new reactors will create large amounts of radioactive waste and likely involve huge additional expenses (Section G).

We begin with some background on the French reprocessing because, as noted above, it is a common point of reference in the present discussion in the United States about reprocessing. France has made more extensive use of reprocessing than any other country. It has supplied reprocessing services to other countries. It has had highly favorable conditions for deployment of reprocessing technologies because the two corporations that own the reprocessing plant and use the resulting plutonium fuel were 100 percent government-owned during the main period of deployment and are still about 85 percent French government-owned.[18]

B. Reprocessing and resource utilization in France

Reprocessing in France is continuing mainly due to the inertia of primarily-government-owned electricity generation and reprocessing corporations (EDF and AREVA respectively) and the political and economic dislocations that closing an established large industrial operation would cause in a largely rural area in Normandy that has scarcely any other industries. After it was clear that the breeder reactor program was not going to fulfill its theoretical promise any time soon, the decision to continue reprocessing in France was not about economics, technical suitability, waste management, or significantly increasing the use of the uranium resource in the fresh fuel.[19] It was driven mainly by the inertia of a system that was government-owned and had already invested a great deal of money and institutional prestige in the technology.

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uranium or plutonium; only the remaining 3 percent or 4 percent is genuinely useless "waste."" The article expresses some reservations about PUREX technology in regard to proliferation. Secretary of Energy Chu has expressed reservations about the French approach to reprocessing because of its proliferation implications and has advocated research on a more proliferation resistant approach. (Chu 2009 pp. 12-13) See below for further discussion.

[17] NRC 2010

[18] EDF 2009. The two corporations are AREVA and Electricité de France (EDF).

[19] All calculations are based on four percent enriched fresh fuel made from natural uranium as the starting point, unless otherwise specified. The results would be similar with any starting enrichment for light water reactors, which are designed to use low enriched fuel (generally less than five percent U-235). Much of the description that follows is based on Makhijani 2001 and Makhijani and Makhijani 2006, unless otherwise mentioned. References may be

1. Light water reactors[20] and reprocessing

Uranium-238 is almost 99.3 percent of the natural uranium resource. It requires about 7.44 kilograms of natural uranium to produce one kilogram of 4 percent enriched uranium fuel, assuming 0.2 percent U-235 in the tails (depleted uranium).[21] This means that about 86.6 percent of the natural uranium resource winds up as depleted uranium. Even if the efficiency of enrichment improved so that only 0.1 percent of U-235 remained in the tails, it would still mean that about 84 percent of the natural uranium resource would wind up as depleted uranium when it is first enriched.[22]

It should also be noted that the vast majority of the uranium in the fresh fuel is still non-fissile U-238. In the case of 4 percent enriched uranium, made from natural uranium, the other 96 percent is uranium-238.[23] A small fraction (about two percent) of this gets converted into plutonium.[24] Some of this is fissioned in the course of reactor operation and therefore provides a portion of the energy output of the reactor. But the vast majority of uranium-238 will remain unused in burner reactors – that is, the type of reactors in use today. Table 1 shows a typical composition of 4 percent enriched fresh fuel made from natural uranium and spent fuel after it has been used to generate energy.

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found in those publications. The ones associated with specific tables, quotes, and new material are provided in this report.

[20] Light water reactors are a specific example of "burner" reactors, which have a net consumption of fissile materials in the course of energy production from fission. Some new fissile material is created, mainly plutonium-239, but the amount of fissile material used (or burned), mainly a combination of uranium-235 and plutonium-239, is greater than the amount of fissile material residing in the irradiated material at the end of the reactor operation period. This discussion is focused on light water reactors (LWRs), and specifically on pressurized water reactors (PWRs), the design used in France. The arguments are essentially the same for boiling water reactors (BWRs). The U.S. commercial nuclear power reactor system consists entirely of PWRs and BWRs. Unless otherwise stated, the examples and figures used in this report are typical of pressurized water reactors. The exact assumptions, such as the enrichment level of the fresh fuel, make no difference to the overall conclusion about the efficiency of resource use in a light-water-reactor system with reprocessing and re-enrichment.

[21] We use 4 percent enrichment as a typical figure. Actual enrichments in pressurized water reactors may range from 3 percent to above 4 percent. During enrichment, natural uranium is separated into two streams – the enriched stream, which is then chemically further processed to make reactor fuel, and the depleted stream, which is also called the "tails." These tails, which consist of depleted uranium, have been accumulating at enrichment plants in the United States and elsewhere. We assume a U-235 content of about 0.2 percent in the tails (i.e., in the depleted uranium). In practice, the U-235 in the tails varies and a typical range generally considered is 0.2 to 0.3 percent. The amount of natural uranium needed to produce a kilogram of fuel will vary according to the enrichment of the fuel used and the percent of U-235 in the tails. The lower the percent of U-235 in the tails, the less natural uranium is needed for a given level of enrichment. Hence the example discussed here is a favorable practical case for maximizing resource use in a light water reactor system.

[22] For simplicity, we ignore losses of uranium during milling and the series of processing steps prior to enrichment. These are small compared to the amount of depleted uranium.

[23] The fraction of U-238 is a little lower in fuel made from reprocessed and re-enriched uranium due to the buildup of other uranium isotopes, notably U-236.

[24] The main isotope (over 50 percent) in the separated plutonium is Pu-239, but there are also substantial amounts of higher isotopes, including Pu-240 and Pu-241. The mixture is known as reactor-grade plutonium. Pu-240 is not fissile. When used as part of MOX fuel in light water reactors some of it gets converted into Pu-241, which is fissile. Pu-240 can fission with fast neutrons and generate energy.

Table 1: Comparison of Isotopic Composition of Uranium in 4 Percent Enriched Fresh Fuel and in Spent Light Water Reactor Fuel, Burnup 45 MWd/kgHM, in percent

Uranium Isotope	Fresh Fuel	Spent Fuel
Trace U	~0.04	~0.02
U-235	4	0.68
U-236	0	0.52
U-238	96	93.05
Pu isotopes	0	0.99
FP	0	4.62
Non-Pu-TRU	0	0.095

Source: Spent fuel values are from IAEA-TECDOC-1535 2007, adapted from Table 27 (p. 74). The total of fission products is calculated as the 100 percent minus the sum of all the listed radionuclides. Fresh fuel values are from IAEA-TECDOC-1529 2007, Table 7.

Notes: 1. Burnup means the amount of heat energy (expressed here in terms of megawatt-days thermal (MWdth) per unit mass of fuel (expressed here in terms of kilograms of heavy metal, which in the case of fresh uranium fuel is simply the uranium content).

2. FP = fission products, non-Pu-TRU = transuranic radionuclides other than plutonium isotopes.

3. Trace U consists of U-234 for fresh fuel and mainly U-234 for spent fuel with much smaller amounts of U-232, U-233 and U-237.

Commercial reprocessing using the PUREX process, the only commercial technology at present, separates the spent fuel into three streams – (i) plutonium, (ii) uranium, and (iii) fission products, plus trace non-fission radionuclides, like neptunium.

France uses most, but not all (see below), of the separated plutonium as a mixed plutonium dioxide uranium dioxide fuel, called MOX fuel for short. It uses depleted uranium to make MOX fuel. However, of the 6.44 kilograms of depleted uranium created in the process of making fresh fuel from natural uranium, in the example we have been using, just over a tenth of a kilogram is used as a component of MOX fuel; most of that remains unused in spent MOX fuel.

France also uses a part of the uranium recovered from spent fuel as a fuel. But this uranium must be re-enriched to the requisite level. To get the same performance as fresh 4 percent fuel, the reprocessed uranium must be enriched to about 4.4 percent,[25] which means that about 87 percent of the recovered uranium becomes depleted uranium waste. Further, roughly 93 percent of this re-enriched fuel is also uranium-238. When this recovered and re-enriched uranium is used as fuel only a small amount of it is converted to plutonium, while most remains unused. If repeated reprocessing and re-enrichment are carried out, the pile of depleted uranium mounts rapidly, while the amount of fissile material dwindles. Further, it should be noted that the process of enriching reprocessed uranium also increases the concentration of uranium-236, which is not fissile; this reduces the usefulness of re-enriched uranium as a fuel.[26]

[25] This is because of the degraded isotopic composition of the uranium. Approximate value read from the graph in IAEA-TECDOC-1529 2007 Figure 7 (p. 12).

[26] See, for instance, the caution of Electrabel/Synatom of Belgium in IAEA-TECDOC-1529 2007 Table 23 (p. 39). Note 2 contains a caution expressed by this company.

The flow of materials in a light water reactor scheme with reprocessing is shown in diagram in Figure 2. It corresponds to the example we have been using: an initial fuel loading of 1 kilogram of fresh (4 percent) low-enriched uranium fuel, 0.2 percent U-235 in the depleted uranium tails at the enrichment plant, and 8 percent plutonium in MOX fuel. We assume that all the recovered uranium is re-enriched.

Only one round of reprocessing and re-enrichment is shown in Figure 2. At the end of the use of the MOX fuel and re-enriched uranium fuel, only about 6 percent of the kilogram of original fresh fuel has been used to generate energy. In turn this is only about 0.8 percent of the 7.44 kilograms natural uranium resource used to make the single kilogram of 4 percent enriched uranium fuels.

Repeated reprocessing, MOX fuel use, and re-enriched reprocessing uranium fuel use does not improve the picture much. This is because most of the remaining spent fuel is left behind as depleted uranium in each round. In fact after five rounds, about 99 percent of the original uranium resource is depleted uranium. This means that the fraction of the uranium resource that can be used in a light water reactor-reprocessing-re-enrichment scheme is one percent or less. This can be raised slightly by reducing the amount of U-235 in the tails below 0.2 percent.

This is a conservative calculation, done as a simple illustration. It ignores the isotopic degradation of both the uranium and plutonium in the second and subsequent rounds of use in a reactor. Specifically, uranium-236 and uranium-234, which are not fissile isotopes and which degrade fuel performance, build up in the fuel as the reactor operates; uranium-236 increases in concentration with re-enrichment. Small amounts of uranium-232 also build up.[27] This isotope has a specific activity (defined as disintegrations per second per unit mass) that is 30 million times greater than natural uranium. Unlike fresh uranium fuel, it quickly generates decay products that emit strong gamma radiation, which creates higher worker radiation risks. Fuel quality requirements limit U-232 to a few parts per billion. As a result, re-enrichment becomes more complex and costly for each round of recycled uranium fuel use in a reactor. The fraction of uranium-236 and uranium-232 must be reduced by blending the enrichment feedstock with natural, un-reprocessed uranium or by blending the enriched uranium derived from reprocessed uranium with enriched uranium originating from fresh ore. Similarly, the isotopic composition of MOX fuel degrades with each round of MOX fuel use and reprocessing; this makes reprocessing even more expensive and the fuel less valuable.

As a result of the above considerations, technical and cost considerations limit the practical ability to reprocessing and re-enrich for more than one round past the first use of fresh fuel made from natural uranium.

We should also note that Figure 2 does not show the losses of the uranium resource at the uranium mill (where, typically, several percent of the uranium is discarded into tailing ponds along with almost all the radium-226 and thorium-230 in the ore) as well as in processing uranium into uranium hexafluoride form needed for enrichment are ignored here for simplicity.

[27] IAEA-TECDOC-1529 2007 p. 5. Uranium-233 and -237 are also formed in very small quantities and have very little radiological impact. Uranium-233 is a fissile material which gives a tiny added benefit to the reprocessed uranium. (IAEA-TECDOC-1529 2007 pp. 7-8)

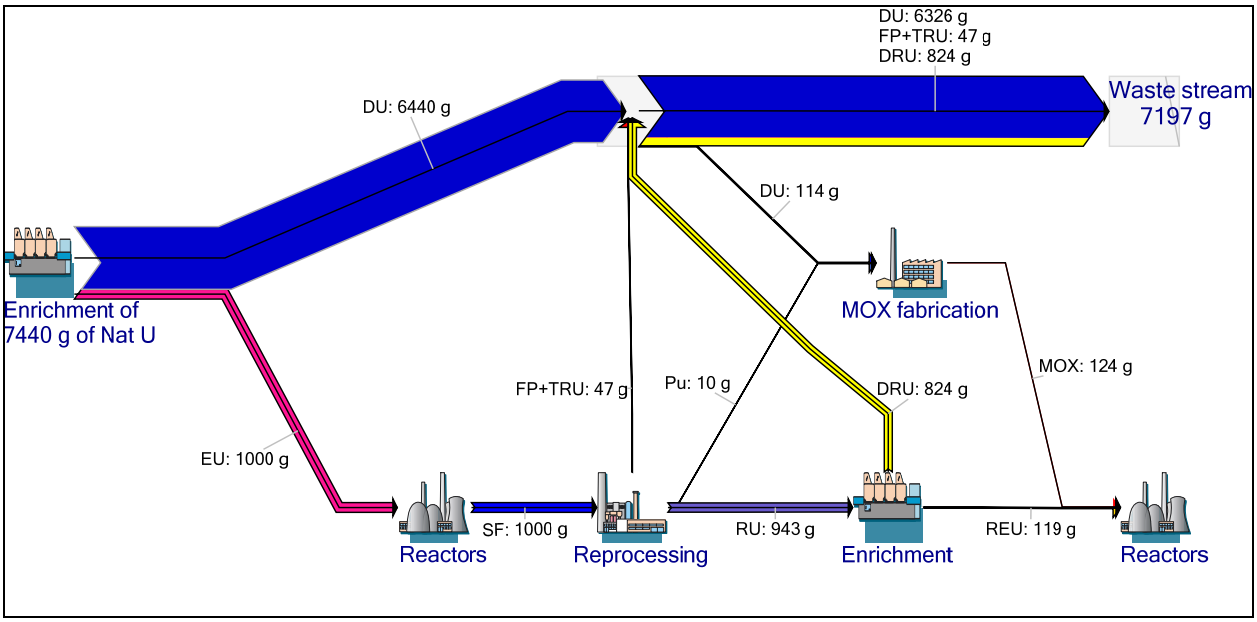

Figure 2: Fuel and Waste Streams in a Light Water Reactor System with Reprocessing and Re-Enrichment for One Kilogram of Fresh Fuel (4% Enriched)

Notes: 1. Nat U = natural uranium; DU = depleted uranium tails (0.2 percent U-235 assumed for this chart); EU = enriched uranium; Pu = plutonium from spent fuel; REU = re-enriched uranium; MOX = mixed plutonium dioxide uranium dioxide fuel; FP = fission products; SF = spent fuel; TRU = transuranic radionuclides other than plutonium isotopes; RU = uranium recovered from spent fuel; DRU = depleted recovered uranium. Pu value rounded up to nearest gram.
2. U-235 in the tails at the enrichment plant = 0.2 percent.
3. The amount of matter converted to energy (according to the famous $E = mc^2$) is very small (much less than one gram per kilogram of fuel) and is ignored in the above diagram.

Even when the initial depleted uranium is left out of the calculation (though it should not be, since it contains most of the natural uranium resource), reprocessing and repeated re-enrichment and MOX fuel use will utilize only about six percent (rounded) of the fuel originally loaded into the reactor, with about two-thirds of that occurring in the initial irradiation and most of the rest occurring in the first round of MOX fuel use. Repeated reprocessing, re-enrichment, and MOX fuel use just does not increase resource use significantly, because most of the uranium becomes part of the depleted uranium stream at each step. Finally, it should be noted that these numbers ignore uranium losses at the uranium mill and in the processing steps needed to make the uranium hexafluoride feed for the enrichment plant. The actual resource utilization based on the uranium content of the ore at the mill is, in practice significantly less than one percent. Fresh fuel plus one cycle of MOX use and re-enrichment uses only about 0.8 percent of the natural uranium resource. This is reduced to about 0.7 percent when the losses of uranium in the processing at the uranium mill and the conversion to uranium hexafluoride are taken into account.

France currently only re-uses a third of the recovered uranium. This means that France uses less than six percent the uranium resource in the original fresh fuel; about 80 percent of this is used in the first round of fresh fuel use prior to reprocessing. In other words, the expense, risk, and

pollution created by French reprocessing (see below) only marginally increases the use of the underlying uranium resource. Further, the re-enrichment is not done in France but in Russia. The depleted uranium from re-enrichment, amounting to roughly 87 percent of the reprocessed uranium by weight,[28] remains behind in Russia.[29]

In sum, the French use only about 0.7 percent of the original uranium resource to create fission energy. The rest is mainly in depleted uranium at various locations, or is piling up as reprocessed uranium that is not being used, or is uranium left in spent fuel of various kinds (including MOX spent fuel). This figure cannot be increased significantly even with repeated reprocessing and re-enrichment so long as the fuel is used in a light water reactor system.

Statements that imply that the French have somehow figured out how to use 90 or 95 plus percent of the uranium resource, such as the one made by Professor Miller, quoted above, are incorrect. At best they are highly misleading because they assume a breeder reactor system (see below)..

C. Reprocessing and radioactive waste

Does reprocessing reduce radioactive wastes destined for a repository? Does it leave behind only relatively short-lived wastes that would decay away in a few hundred years, relieving the need for a deep geologic repository? What about the wastes issues created by reprocessing? We briefly take up these questions in this section.

The PUREX process is an aqueous process that uses large amounts of nitric acid and organic solvents to separate the plutonium, uranium, and fission products (plus minor actinides) into separate streams of material. The fission products contain the vast majority of the radioactivity at discharge from the reactor.[30] Reprocessing channels these into a liquid high-level waste stream. These liquid wastes are then mixed with molten glass and poured into metal canisters – a process called vitrification. The resulting high-level radioactive waste canisters are stored onsite. Neither France nor any other country has a deep geologic repository for high-level waste.

Almost all the heat generation in spent fuel, a major issue for repository disposal, is by the fission products in it. Whether the fission products are in spent fuel or mixed with molten glass makes almost no difference to the heat generation. Very long-term heat generation in the high-level waste (more than 1,000 years) is reduced somewhat, but the most important considerations having to do with repository space have to do with the initial heat load. That can be reduced by storing spent fuel or storing high-level vitrified waste above ground for many years before disposal in a repository.

[28] The exact percentage will depend on the composition of the recovered uranium and degree of enrichment. This assumes 4.4 percent enrichment, as discussed above.
[29] France DGEC 2009 pp. 2-3
[30] Murphy 1996 Figure 9 (p. 18)

A second consideration is that MOX spent fuel has even more long-lived transuranic isotopes than spent uranium fuel. This makes the long-term heat load from MOX spent fuel disposal significantly higher than uranium spent fuel. Reprocessing MOX spent fuel is a losing economic proposition. Even if it is done, the resulting wastes will be even more problematic.

A third consideration is that reprocessing, re-enrichment, and MOX fuel use do nothing to eliminate long-lived fission products. These are among the most troublesome for long-term water pollution that is likely to be associated with repositories. Iodine-129 (half-life 16 million years), cesium-135 (half-life 2.3 million years), and technetium-99 (half-life 213,000 years are important long-lived fission products. There are also other problem radionuclides that are very long lived, like chlorine-36 and tin-126.

Some advanced, secondary reprocessing and reactor schemes have been proposed to deal with some long-lived transuranic radionuclides. This can be done in some cases; it is very difficult in others and technically infeasible in yet others. All of the proposed schemes add to the expense and technical problems associated with reprocessing without getting rid of the problem of long-lived radionuclides.[31]

Fourth, reprocessing generates waste highly contaminated with plutonium, known in the United States as "transuranic waste" or TRU waste for short, as well as other wastes known as Greater than Class C waste. All of this waste must also be disposed of in a repository, according to French regulations and are presumed to be destined for a deep geologic repository under U.S. regulations as well. TRU waste originating in the U.S. nuclear weapons program is being disposed of in a deep geologic repository in New Mexico. The Department of Energy has estimated that the combined cumulative volume of wastes destined for deep geologic disposal, including vitrified waste, is estimated to be about six times that of direct disposal of spent fuel, which is the current U.S. policy. Most of this volume consists of Greater than Class C waste, [32] which can be packed more closely than either spent fuel or vitrified high-level waste. These estimates were made on a life-cycle basis for comparing the various approaches to nuclear energy generation.

There are short-term waste considerations with reprocessing as well. France stores the liquid acidic wastes containing almost all the fission products in stainless steel tanks at its La Hague reprocessing plant on the Normandy peninsula. These tanks must be cooled constantly; loss of cooling for a few days could result in a catastrophic accident. The tanks did lose cooling for a few hours in 1980, but fortunately cooling was restored and an accident was prevented.[33] More recently, in April 2009 and January 2010, the tanks at Sellafield, the site of the British reprocessing plant, suffered a loss of coolant water in several tanks.[34]

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[31] A list of long-lived radionuclides and proposals to transmute them (or not) can be found in Makhijani and Zerriffi May 2000. A report examining the associated technologies and concerns in detail was published by IEER in 2000. See Zerriffi and Makhijani 2000.

[32] DOE/EIS-0396 GNEP Draft Table 4.8-6 (p. 4-139)

[33] ACRO 2005

[34] For 2010: CORE 2010 and Irving 2010; for 2009: West Cumbria 2009 Section 2.2.4 and Irving 2009

A comparison of radioactive waste generated by a system of 200 nuclear light water reactors without and with reprocessing reactors over their operating lifetime as estimated by the DOE is shown in Table 2.

Table 2: Cumulative waste volumes for 200 GW Light Water Reactor (LWR) Systems, in m^3

System	Spent fuel or High-level waste	GTCC waste	Total repository waste	Low-level waste	Annual radiological transports (rail plus truck)	Comments
LWR once-through	70,990	2,500	73,490	150,000 to 585,000	165,000	
LWR with reprocessing	52,000	407,000	459,000	1,740,000 to 2,175,000	1,224,000	~100 million liters of liquid radioactive waste reprocessing discharges per year (Note 2)
Ratio with/without reprocessing	0.73	163	6.2	3.7 to 11.6 (max to max and min to min)	7.4	

Source: DOE/EIS-0396 GNEP Draft Table 4.8-6 (p. 4-139)
Note: 1. Total volume to be disposed of in a repository calculated by adding spent fuel or high-level waste volume to GTCC volume. GTCC stands for Greater than Class C Waste.
2. For discussion of liquid discharges, see below.
3. Waste volume is calculated over a 50-year life-cycle.

We have used DOE estimates, since French estimates for reprocessing versus non-reprocessing systems are not readily available on a cumulative, life-cycle basis. Rather than reducing the waste problem, the French have increased the volume greatly. The heat load problem is likely to be a comparable problem if direct disposal of MOX fuel is included.[35] They will generate about six times the total volume of wastes to be disposed of in a repository. And the low-level waste and transport volumes are multiplied several fold.

France has faced intense opposition to its repository program and its experience has been quite similar to that in the United States. Starting with an ambitious program to characterize several sites in different geologic media, intense opposition was among the factors that reduced the program to characterizing a single site near Bure in northeastern France.[36] According to the calculations of ANDRA, the French nuclear waste agency, iodine-129 would be the main source of long-term dose in case of a failure of repository seals.[37]

Reprocessing also generates large amounts of other radioactive waste. The La Hague plant discharges about 100 million liters of liquid wastes into the English Channel each year.[38] These

[35] French policy is not yet clear regarding the ultimate disposition of MOX spent fuel. At present it is being stored.
[36] France. Assemblée nationale 2006, Statement by Christian Bataille; Boilley 1998; and France Mission 2000
[37] Makhijani 2005 Slide 15
[38] AREVA 2009-06. The discharges of radionuclides other than tritium have declined but discharges of tritium, which dominate the radioactivity of the discharges, are about the same as a decade ago. (AREVA 2008)

discharges have contaminated the oceans all the way to the Arctic,[39] drawing protests from neighboring countries, which have asked France (and Britain) to stop reprocessing, and by implication, to stop the discharges.[40]

Further, France does not reprocess all of its spent fuel. Currently, about 850 metric tons of the 1,200 metric tons that are discharged every year are reprocessed, leaving 350 metric tons as spent fuel. Hence, besides accumulating volumes of high-level and intermediate level waste, France had to also build spent fuel storage facilities at La Hague, which AREVA is now planning to expand. Starting in 2010 the 850 metric tons were to be increased to 1,050 metric tons per year covering all uranium spent fuel, according to a framework agreement between AREVA and EDF at the end of 2008 that would last until 2040.[41] This would leave only MOX spent fuel unreprocessed, which amounts to about 150 metric tons per year.

In sum:

- France needs a deep geologic repository and it does not yet have one. Public opposition to the French repository program has been intense. For instance, research on a second repository in granite was stopped due to public opposition.
- Reprocessing has increased the volume of waste to be disposed of in a deep geologic repository (high-level waste plus Greater than Class C waste) in France, based on DOE lifecycle waste estimates. Low-level wastes and waste transports are also estimated to be greater.
- France discharges about 100 million of liters of liquid radioactive waste into the English Channel each year and has polluted the oceans all the way to the Arctic, drawing protests from neighboring governments who have asked France to stop reprocessing on this account.
- Reprocessing has created additional risks in the form of the need to store liquid high-level wastes, which need constant cooling, and of surplus separated plutonium.

Some additional comment on the last point is warranted. Loss of cooling to a liquid high-level waste storage system resulted in an explosion and a very large release of radioactivity in the Soviet Union in 1957.[42] In 2009, the Norwegians prepared an estimate of the consequences for Norway of a release of 0.1 to 10 percent of the stored liquid waste at Sellafield, which is the British commercial (and in the past military) reprocessing site in northwestern England. It did not estimate the mechanisms or probability of such an accident. The potential for such an accident is recognized. One mechanism could be a prolonged (several-day) loss of cooling to the tanks.

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[39] OSPAR 2000 p. 61

[40] OSPAR 2000 Decision. OSPAR, the Oslo-Paris accords group. Its decisions are binding on its members only if they affirm them. OSPAR decided by a large majority (11 of 15 members) on a non-reprocessing policy for managing spent fuel. But since France and Britain abstained, they are not obliged to implement the decision. Luxembourg, which was absent, later agreed with the OSPAR decision.

[41] Dubillot 2008

[42] IPPNW and IEER 1992

In addition to a range of source terms, the Norwegian Radiation Protection Authority also modeled releases under different meteorological conditions.

> Norway received large amounts of ^{137}Cs fallout under the scenarios (an accidental release of between 0.1 – 10 % of the total HAL [Highly Active Liquors] inventory) of between 10 – 5000 kBq/m^2, especially along the west coast. Model simulations resulted in between 0.1 – 50 times the maximum ^{137}Cs fallout experienced in Norway after the Chernobyl accident. For the chosen weather situation, fallout started to occur over Norway only 9 hours after the hypothetical release.[43]

The Authority only modeled a single radionuclide. The liquid radioactive wastes contain several long-lived radionuclides in significant amounts. Notably, strontium-90 is present in concentrations comparable to cesium-137.

D. Costs of reprocessing in France

Prior to the recent contract to increase reprocessing from 850 to 1,050 metric tons per year, France was spending about 800 million euros per year extra in fuel costs, compared to uranium fuel, for using MOX fuel.[44] This amounts to about 40 million euros per reactor per year using 30 percent MOX core. It is about two euro-cents per kWh for the electricity generated from this fuel. With the new contract to increase reprocessing, added costs on this basis will be about 1.2 billion euros. The exchange rate of the euro to the U.S. dollar has varied enormously since the introduction of the euro as a banking currency in 1999 and as a currency of everyday use in 2001, from just over 80 U.S. cents to the euro to about $1.60 per euro. If we use the rate at which the euro was issued, 1.17 dollars per euro, the added costs come to about $1.4 billion. At this exchange rate, the added cost of electricity generated from MOX fuel is about U.S. 2.3 cents per kWh, which is more than the present fuel and non-fuel operating cost of U.S. nuclear power reactors.[45] We have rounded this to a single significant figure of 2 cents per kWh in the rest of this report.

The added costs were recognized by Eléctricité de France (EDF) in 1989 at the start of the MOX fuel use, even though it did not see a justification for stopping the program on economic grounds. According to an EDF memo from the time:

> In view of the commitments already made, and even though MOX is significantly less competitive than natural uranium, it appears that the reprocessing option must be maintained and that UP2 be indeed transformed into UP2 800. Challenging this option has no economic basis; it would also have great global repercussions that would be detrimental to the nuclear industry.[46]

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[43] Norwegian Radiation Protection Authority 2009 p. 5

[44] Makhijani 2001 footnote 26 and associated text. About the same added cost was estimated based on an official French report, Charpin, Dessus, and Pellat 2000 p. 56 of the pdf version (in Chapitre 1, section 3.4)

[45] NRC 2009-2010 Table 2 (p. 21) states the fuel and non-fuel operating and maintenance costs for 2007 to be $20 per megawatt-hour, which equals 2 cents per kWh.

[46] EDF 1989 p. [7]. Translation by Annie Makhijani. The La Hague reprocessing plant UP2 was eventually upgraded and is now known as UP2-800. There is a second plant at La Hague, known as UP3

Reprocessing and MOX fuel use continues in France not because of a significantly better use of the natural uranium resource, economic advantage, or waste reduction benefits. Rather it continues despite the failure of France's breeder reactor program for which it was originally envisioned in 1974[47] because both companies involved in it are mainly government-owned and they have found it impossible to stop the program despite its many drawbacks.

1. A note on British reprocessing compared to France

It is important to note that, despite the poor economic, waste, and environmental outcome of French reprocessing (compared to once-through fuel use), France has, in the past two decades or so, done commercial reprocessing about as well as it can be done, operating plants at full capacity and ramping up MOX fuel use to 20 reactors, each of which uses MOX for 30 percent of its core.

By contrast, the corresponding British PUREX plant, called THORP (THermal Oxide Reprocessing Plant), has been a case study in operating problems, leaks, shut-downs, and low capacity factors.[48] The plant is located at Sellafield, in northwestern England. Even as it incurs huge costs and environmental liabilities, Britain has been accumulating separated plutonium to an even greater extent than France. The surplus from the PUREX plant as well as another reprocessing plant stored at the site is in excess of 100 metric tons. A primary reason is that Britain has not used any MOX fuel in its commercial reactors; in fact, it has no practical way to use a significant amount of this plutonium in its reactors.[49] As with France, Britain's neighbors, including Ireland, have protested its radioactive discharges into the seas (the Irish Sea in this case).

E. Reprocessing and proliferation

1. PUREX process and proliferation

A simple fact should first be noted. Separated plutonium made in the course of commercial reactor operation can be used to make nuclear bombs. It has a different isotopic composition than weapon-grade plutonium and would not be the desired material for bomb making were weapon-grade material available. However, the different isotopic composition is not a bar to making weapons like the one that devastated Nagasaki on April 9, 1945.

The Department of Energy has noted the following about reactor-grade plutonium and bombs:

[47] EDF 1989 p. [1]

[48] It was commissioned in 1994 and is currently operating at partial capacity; it is slated to be shut in 2011. (World Nuclear News 2010)

[49] Further most of the separated plutonium is now so old, that it has built up a significant amount of americium-241 from the decay of plutonium-241. Such plutonium would have to be chemically processed again, involving even more expenditures, if it to be used as reactor fuel.

> Designing and building an effective nuclear weapon using reactor-grade plutonium is less convenient than using weapon-grade plutonium, for several reasons….[B]ackground neutrons from Pu-240 can set off the reaction prematurely, and with reactor-grade plutonium the probability of such "pre-initiation" is large. Pre-initiation can substantially reduce the explosive yield, since the weapon may blow itself apart and thereby cut short the chain reaction that releases the energy. Nevertheless, even if pre-initiation occurs at the worst possible moment (when the material first becomes compressed enough to sustain a chain reaction), the explosive yield of even a relatively simple first-generation nuclear device would be of the order of one or a few kilotons. **While this yield is referred to as the "fizzle yield," a l-kiloton bomb would still have a radius of destruction roughly one-third that of the Hiroshima weapon, making it a potentially fearsome explosive. Regardless of how high the concentration of troublesome isotopes is, the yield would not be less.**[50]

All countries that have commercial reprocessing at present – France, Britain, Russia, Japan, and India – have surplus stocks of separated plutonium, with the total amounting to about 250 metric tons, about the same as global military plutonium stocks. Britain and France have the largest stocks. France has about 80 metric tons of it at La Hague, enough to make 11,000 to 12,000 nuclear bombs;[51] Britain has more than 100 metric tons at Sellafield, enough to make about 14,000 nuclear bombs.

While Professor Miller states that "no plutonium has ever been diverted from French or British recycling facilities for weapons production"[52] a close examination shows that this statement is somewhat misleading as to the proliferation implications of reprocessing in these two countries. In fact, both started reprocessing to acquire plutonium for their weapon programs. Further, both France and Britain reprocess spent fuel for third countries, including Japan. While Japan has a stated policy of using separated plutonium as MOX fuel in its reactors (and, in fact, has its own reprocessing facilities as well), it has only recently used any MOX fuel in a commercial nuclear power reactor.[53]

Japan's stocks of commercial plutonium keep rising. At the end of 2008, Japan had 9.6 metric tons of separated plutonium either as pure plutonium or as unirradiated MOX fuel. A further 25.2 metric tons of fissile isotopes of plutonium (about 38 metric tons total plutonium) stored in other countries.[54] Japan owns enough separated plutonium at home and abroad to make more

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[50] DOE 1997 p. 38. Emphasis added.

[51] The amount of commercial plutonium needed to make a bomb is somewhat greater than if the isotopic composition corresponds to weapons-grade plutonium, which has about 93 or 94 percent plutonium-239. According to Kang and von Hippel 2005 it takes about a third more commercial grade plutonium to make a bomb compared to weapon-grade plutonium. Using a figure of 5 kilograms per bomb for weapon-grade plutonium, we get a figure of 6.3 kilograms per bomb for commercial grade plutonium. We use a value of 7 kilograms in this report as a conservatism. Data on stocks of commercial and military plutonium can be found at Albright and Kramer 2005 Table 2 (p. 6) and Table 3 (p. 7).

[52] Miller 2009

[53] AREVA 2009-12. Britain, which has over 100 metric tons of separated plutonium in storage at Sellafield, has not used any MOX fuel in a commercial power reactor. In 1999, a British assessment declared that this plutonium had no economic value. (House of Lords 1999 pp. 63-66)

[54] IAEA 2009

than 5,000 nuclear bombs. While the matter does not get much publicity, there is an active debate in Japan whether it should develop nuclear weapons. The rise of China, the acquisition of nuclear weapons by North Korea, and the increasing strains in its alliance with the U.S. are all factors in this debate. In 2002, Ichiro Ozawa, the head of the Democratic Party of Japan until mid-2009,[55] which now rules Japan, made comments about the potential for Japan to make nuclear weapons from its commercial power assets. According to a newswire report from Reuters:[56]

> The leader of Japan's opposition Liberal Party, Ichiro Ozawa, said on Saturday it would be a simple matter for Japan to produce nuclear weapons and surpass the military might of China if its neighbour got "too inflated."
> …
> "It would be so easy for us to produce nuclear warheads. We have plutonium at nuclear power plants in Japan, enough to make several thousand such warheads," he said.

The argument about whether Japan should become a nuclear weapon state goes back at least to its consideration of the Nuclear Non-Proliferation Treaty. In 1968, a Japanese Foreign Ministry document indicated that it was a "cost-benefit" calculation as to whether Japan should rely on the United States nuclear arsenal or acquire its own. Japan has never made public the internal Foreign Ministry documents indicating that it abandoned the thinking in the 1968 document when it ratified the NPT despite public demands that it do so. [57]

Given that North Korea is the first state to use a supposedly commercial reactor and associated reprocessing plant to make nuclear bombs, Professor Miller's attitude seems rather cavalier. In fact, Japan could quickly become a nuclear weapon state using its commercial separated plutonium. I discussed this with the late Herbert York, the first director of Lawrence Livermore National Laboratory, one of the two U.S. nuclear-weapon design laboratories, in 2001, in an on-the-record interview:[58]

> Makhijani: This wasn't a planned part of my interview, but since we are on the subject, what about if the designs of these complex weapons were available, how long would it take to recreate them?
>
> Dr. York: If you shut everything down – eliminated the entire U.S. nuclear weapons infrastructure, but had the designs, one could recreate them in a short time, two or three years.
>
> Makhijani: How about countries like Japan?
>
> Dr. York: What do you think?
>
> Makhijani: My speculation has been that Japan would take six months to become a nuclear weapons state.

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[55] Wikipedia Liberal Party Japan 2009 and Wikipedia Democratic Party of Japan 2009. In 2002, Ozawa was still in the Liberal Party, which later merged with the Democratic Party of Japan.
[56] Reuters 2002
[57] Makhijani 1995
[58] York 2001

> Dr. York: That's right. I say that too. They wouldn't have the very sophisticated weapons, but they could be a nuclear weapons state in six months. Almost any western European country and a few other countries could do that. Switzerland could do it [for example].

The central proliferation issue associated with reprocessing it that it results in separating a material that can be used to make bombs. Getting weapons-usable material is the main obstacle to making nuclear weapons. As regards potential proliferant states, most of the rest is mainly a matter of intentions, which as history shows in ample measure, can change.

2. Advanced reprocessing

Since the PUREX technology is a potential source of proliferation, despite sanguine statements made by some, a number of alternative reprocessing technologies and reactor schemes have been proposed. Ostensibly these would enhance the utility of reprocessing as a waste management tool and/or increase the utilization of uranium resources. As to waste management, it is generally recognized in serious technical discourse, if not always in public statements, that the PUREX process, which is the only commercial reprocessing technology at present, does not deal with minor actinides, notably americium-241 (half-life 432 years) and neptunium-237 (half-life 2.14 million years), which are created in significant amounts in reactors. The former is created as the decay product of plutonium-241 and the latter via successive neutron absorptions by uranium-235.[59]

Alternative separation and transmutation technologies generally involve further separation of long-lived trace radionuclides by various chemical means and their repeated irradiation in nuclear reactors. None can eliminate long-lived radionuclides sufficiently to obviate the need for a deep geologic repository. Further, the amount of depleted uranium from commercial and military activities is now so large that it will be practically impossible to use it as a resource, given the technical, cost, and proliferation problems as well as the very long time frame and huge number of breeder reactors that would be needed. This depleted uranium has a high enough specific activity and other characteristics that it should be required to be disposed of in a deep geologic repository in a manner similar to military transuranic waste (TRU waste).[60]

Sufficient quantities of long-lived wastes would remain with any reprocessing approach to require a repository, raising a question about whether these "transmutation" strategies, advertised as useful for turning long-lived into short-lived radionuclides, are waste management strategies or simply a device to get money for nuclear energy R&D.[61] Consider, for instance the following

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[59] Pu-239 + neutron → Pu-240 + neutron → Pu-241 → Am-241 + beta particle (electron); and U-235 + neutron → U236 + neutron → U-237 → Np-237 + beta particle (electron)

[60] TRU waste from U.S. nuclear bomb production is being disposed of at the Waste Isolation Pilot Plant, a deep geologic repository in New Mexico. France has also designated such wastes for deep disposal, but does not have an operating repository as yet.

[61] The transmutation issue is analyzed in detail in Zerriffi and Makhijani 2000.

statement by Paul Govaerts of the Belgian Nuclear Research Center, made at a transmutation conference in 1998.[62]

> Research on partitioning and transmutation is rather seductive to all of us. It requires new reprocessing techniques, new fuel developments, additional nuclear data, new reactors and irradiation facilities, new waste treatment and disposal concepts, and specific safety studies. The global nuclear scientific and engineering community is challenged by this opportunity.
> …
> Everybody realises however that this voyage to the promised land will pass a desert with a lot of mountains and that we are not so sure that the horizon will be as bright as one can hope.

We will only consider a single advanced reprocessing technology in this report, since it the one under consideration in the United States and since it has been promoted as "proliferation-resistant." An analysis of various other techniques can be found in a report published by IEER in the year 2000.[63] We also provide an overview of the proliferation implications of advanced reprocessing technologies.

3. Electrometallurgical processing

In the United States, the alternative reprocessing and reactor scheme now favored as a waste management strategy by breeder-reactor advocates in the DOE laboratories centers on the Integral Fast Reactor (IFR). This is the familiar sodium-cooled fast breeder reactor married with a new reprocessing technology called pyroprocessing or electrometallurgical processing. This differs from the aqueous chemical process that is PUREX in that it involves electrolytic separation of the constituents of spent fuel. The term "integral" to describe the scheme refers to the location of the reprocessing plant at the same site as the reactor. The theory is that the separated fissile materials would not leave the site; hence the proliferation vulnerabilities associated with transportation of fissile material can be eliminated and accountability of the material can be increased, thereby making the technology more proliferation resistant relative to the PUREX technology. Further, unlike the PUREX process, electrometallurgical processing, when operated with an IFR, is designed so as to not separate pure plutonium. Rather, a mixture of actinides, with some fission products, is separated, making it more complex to make a nuclear weapon. In theory, this also increases proliferation resistance.

Proliferation concerns are associated with the PUREX process both because it separates pure plutonium for commercial purposes and because it puts mixed oxide fuel, from which it is not very difficult to separate out plutonium, on the roads. Further, fresh MOX fuel would have to be stored at commercial reactors; this would raise far more security concerns than low-enriched uranium, which is much more difficult to process into weapons usable material. In light of this, the following advantages are claimed for the reprocessing scheme associated with the IFR:[64]

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[62] Govaerts 1998
[63] Zerriffi and Makhijani 2000
[64] Berkeley Nuclear no date. This is a description of the IFR system from the University of California, Department of Nuclear Engineering. Some of the specifics of reactor operation as well as two 1986 safety tests are from the

1. The reprocessing plant would be at the reactor site, making diversion of fissile material much more difficult.
2. "In the IFR, the nature of the fuel reprocessing is such that the fuel remains highly radioactive at all times…. In any event, IFR fuel is not suitable for weapons without extensive processing in very expensive facilities."
3. A mixture of radionuclides is separated for use as a fuel, instead of only plutonium isotopes, as is the case with PUREX technology today. This would make the IFR proliferation-resistant.

In addition, Wymer et al. have pointed out that some radionuclides in the transuranic mix, like plutonium-238 and curium-242, have much higher specific activities than plutonium-239. The heat produced by the material would make it more difficult to make nuclear weapons and may make them unstable. However, a small aqueous separations "finishing" process could be added to separate the plutonium.[65]

These non-proliferation merits must be seen on a relative basis. The act of separation of any material that can be used to make nuclear bombs greatly increases proliferation risks relative to once-through fuel use, in which spent fuel is stored for a time and then disposed of in a deep geologic repository. The above claims also have some technical substance, but they do not address the principal problems associated with the technology.

The mix of transuranic radionuclides separated using electrometallurgical processing can be used quite as effectively to make a nuclear weapon as the reactor-grade plutonium separated in today's PUREX plants. Further, since neptunium-237 and americium-241, the principal non-plutonium radionuclides that would be in the separated mix of actinides, are both fissile materials, it requires just about a fourth more material to do so than with the pure plutonium that results for PUREX process separation. It takes about a third more reactor-grade plutonium to make a nuclear bomb than weapon-grade plutonium. The net result is that it would take less than 10 kilograms of electrometallurgical separated material to make a nuclear bomb. In both cases, the amount of material is considerably less than the amount of highly enriched uranium needed for a bomb. The difficulty of making nuclear bombs using a transuranic mix is generally comparable to using reactor-grade plutonium, which also contains troublesome isotopes that could cause "pre-initiation" of a nuclear weapon.[66] The material is more difficult to handle and the pit would have to be cooled to prevent excessive heating, but these problems can be overcome, for instance, by using a pre-cooled pit.[67]

The actual process of making nuclear weapons can be rendered more complex if gamma-radiation-emitting fission products are in the separated fuel mix in sufficient amounts to make handling the material much more dangerous that pure reactor-grade plutonium. An inherent

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operation of a pilot plant called "Experimental Breeder Reactor II" or "EBR II" at the Argonne National Laboratory – West in Idaho. The EBR II, shut down in 1994, was a 62.5 megawatt-thermal reactor. This is about 2 percent of the thermal rating of a typical commercial nuclear power plant.

[65] Wymer et al. 1992 pp. 52-54

[66] Kang and von Hippel 2005

[67] Kang and von Hippel 2005

limitation on this is that fission products interfere with the process of maintaining a chain reaction in the reactor. There only two radionuclides with high enough gamma radiation rates and long enough half-lives to make the work of using the electrometallurgical processing product much more difficult. They are:

- Cerium-144 (Ce-144); half-life 0.78 years
- Europium-154 (Eu-154); half-life 8.8 years

The other radionuclides in this group (Lanthanides) are either too short-lived (Praseodymium-144 (Pr-144)) or have radiation levels that are too weak to be effective (Samarium-147 (Sm-147)), Europium-155 (Eu-155), for instance).

Further, of the two suitable radionuclides, electrometallurgical processing separates out Eu-154 from the transuranics. This leaves only Ce-144 as an effective radiation barrier to potential fabricators of nuclear bombs. But given that the half-life of Ce-144 is only 0.78 years, the radiation level declines in a few years to levels that would not deter a determined non-state group or a state with no other fissile material.[68]

Nuclear weapon states with established access to weapon-grade materials to use in nuclear bomb programs would be highly unlikely to resort either to reactor-grade plutonium from PUREX plants or to a transuranic mix from electrometallurgical processing. That is not the proliferation issue. Rather, it is the development and refinement of a technology that could provide nuclear-weapons-usable materials to states that do not now have them, and possibly also to non-state groups.

The PUREX process consists of a huge chemical factory using an aqueous process. Hence while it is cumbersome from an engineering standpoint, it has the proliferation advantage of being easily detectable. In contrast, electrometallurgical processing is much more compact. The heart of the system is the electrorefiner, which is can be as small as one meter (about 3.3 feet) in diameter.[69] This makes the electrometallurgical system much easier to hide than a PUREX process, much in the same way that gas centrifuges used for uranium enrichment are much easier to hide than the enormous gaseous diffusion plants that were first used for enriching large amounts of uranium. The Iranian example of building a large gas centrifuge plant secretly provides an example of what could happen in the plutonium arena once the size of reprocessing plants is greatly reduced.

While the U.S. proposals for the IFR have focused on the reactor and reprocessing being collocated, this is not an essential technical element of the approach. In fact, a centralized electrometallurgical installation is among the options that could be considered in the context of a plan to build many fast neutron reactors.[70] If a country or a non-state group decided to secretly build a small plant for weapons purposes, it could be done at locations that are not under safeguards. The main issue in such a case would be to procure spent fuel, which is the raw material for reprocessing systems. This is a non-trivial problem, but it should be noted that spent

[68] Kang and von Hippel 2005 pp. 174-176
[69] Chang 2007 p. 168
[70] Wymer et al. 1992

fuel is not safeguarded in the same way as separated plutonium. Indeed, spent fuel has been inadvertently lost from nuclear power reactor storage pools in the United States without being detected for many years. For instance, a bent fuel rod and a displaced fuel rod were put into a canister, which was stored in 1972 in the spent fuel pool of the Millstone 1 reactor in Connecticut. The canister could not be located in 1980. The matter came to light only when the reactor was put up for sale in 2000. The two fuel rods contained about 40 grams of plutonium. They may have been dumped into a low-level waste disposal facility or may have been in the pool at an unknown location;[71] the NRC simply could not tell in 2001,[72] 21 years after the plant operator first could not identify where the canister was in the spent fuel pool.

At present, electrometallurgical processing is not a fully developed commercial technology. It would be very difficult for proliferant states that do not now have reprocessing or uranium enrichment facilities or both to develop this technology fully. But once it is developed, it would be difficult to keep it under wraps. The know-how will spread. The lessons of gas centrifuges for enriching uranium, which were difficult to master, are also instructive. Today it is the technology that poses the most acute proliferation concerns in the commercial nuclear power system.

Other than not making the plutonium in the first place, keeping it in spent fuel, mixed with large amounts of uranium and highly radioactive fission products, including cesium-137, which is a strong gamma emitter, is by far the most proliferation-resistant approach to managing the proliferation issues arising from the back end of commercial nuclear power.

4. Overall assessment of proliferation potential of advanced reprocessing technologies

All reprocessing technologies that are under consideration as "proliferation resistant" (because they do not separate pure plutonium, among other possible features) are vulnerable to proliferation. In fact, for proliferant states that do not now have separated fissile materials, the additional barriers are not significant compared to separating plutonium from spent fuel. A review of advanced technologies and their proliferation potential was published by Brookhaven National Laboratory. Its authors, who were expressing their own views in the paper, were from several DOE laboratories, including weapons laboratories like Los Alamos National Laboratory and Sandia National Laboratory as well as the lead laboratory for nuclear power in the United States, the Idaho National Laboratory, and the laboratory that has had the lead in the development of the sodium-cooled reactor in the United States, Argonne National Laboratory.[73]

The authors considered a number of criteria related to proliferation:

- The technical sophistication needed to handle the nuclear materials.
- Cost of the technology and time and staff required.

[71] NRC 2001
[72] Meserve 2001
[73] Bari et al. 2009. We note here that the paper is not oriented to a recommendation of direct disposal of spent fuel instead of reprocessing. It is directed rather towards safeguards issues in the event a decision is made to pursue reprocessing.

- Type of fissile materials involved and their suitability for making nuclear explosives.
- The ease with which safeguards can be applied and the costs and capabilities needed to implement the safeguards.
- The potential consequences of the proliferant party's actions.

They grouped various advanced reprocessing approaches into four groups (W, X, Y, Z), with electrometallurgical processing in Group W, according to their technical and material characteristics to compare each to the PUREX process. (The PUREX process is regarded as the most proliferation-prone reprocessing technology.) As discussed above, it is the one in use today. The Bari et al. paper's conclusions were that the differences among the various advanced reprocessing technologies, so far as proliferation potential is concerned, "are not very significant" except in the case of a set of technologies that separate a mixture of plutonium and neptunium. In that case the difference with PUREX is "small."[74]

Moreover, once states have mastered reprocessing technology, the time required to purify material mixtures and separate pure plutonium "ranges from a few days to a few weeks."[75] Given past experience, this would present huge challenges to timely detection of diversion and verify stocks. Action to stop the program and reverse the process is complex and uncertain and would involve many risks for all parties. The overall conclusions of Bari et al. are as follows:

> In sum, for a state with pre-existing PUREX or equivalent capability (or more broadly the capability to design and operate a reprocessing plant of this complexity), there is minimal additional proliferation resistance to be found by introducing Group W [which includes electrometallurgical processing], X, or Y processing technologies when considering the potential for diversion, misuse, and breakout scenarios.
>
> In a nuclear material theft scenario involving non-state actors, Groups W, X, and Y provide some advantage over Group Z (whose product is plutonium or plutonium not separated from neptunium). These advantages arise from the additional cost, time, and technical difficulty that would be entailed in further processing by a non-state actor of any Group W, X, or Y products to obtain pure plutonium.
> …
>
> This evaluation found only a modest improvement in reducing proliferation risk over existing PUREX technologies, and these modest improvements apply primarily for non-state actors. This study reinforces the importance (1) limiting reprocessing activities to a small number of states with strong nonproliferation credentials and (2) developing effective and transparent international safeguards for any reprocessing technologies selected for use in a comprehensive program.[76]

However, despite the hope of many that reprocessing can be restricted to a small number of states, this is a strategy that is unlikely to be acceptable to the very states that may have the desire to develop commercial nuclear technology with the aim of developing latent nuclear weapons capability. For instance, South Korea has recently expressed a desire to develop and implement reprocessing as a way to manage spent fuel.[77]

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[74] Bari et al. 2009 p. 6 of pdf
[75] Bari et al. 2009
[76] Bari et al. 2009 pp. 6-7 of pdf
[77] NTI 2010

Commercial nuclear power ambitions now extend to major oil exporters in the Persian Gulf. But a news report of an event announcing the interest makes clear that one eye is towards Iran and the other is towards Israel:

> The leaders of Saudi Arabia, Bahrain, Kuwait, Oman, Qatar, and the United Arab Emirates called for a peaceful settlement of the conflict over Iran's nuclear program, and demanded that Israel, the only country in the Middle East believed to have nuclear weapons, join the nuclear Non-Proliferation Treaty.
>
> Speaking to reporters after the summit, Foreign Minister Prince Saud Al-Faisal said the GCC states' intention to pursue civilian nuclear technology was not a "threat" to anyone. "We are announcing our intention to pursue the ownership of nuclear technology for peaceful (purposes)," he said.
>
> "It is not a threat. It is an announcement so that there will be no misinterpretation of what we are doing. We are not doing this secretly. We are doing it openly," he said.
>
> "We want no bombs. Our policy is to have a region free of weapons of mass destruction," the prince added. "This is why we call on Israel to renounce (nuclear weapons)." The "original sin" was from Israel as it established a nuclear reactor with the only purpose of producing nuclear weapons, Prince Saud said.[78]

Mohammed ElBaradei, the just retired Director General of the International Atomic Energy Agency, stated in 2008 that the new interest in nuclear power by many developing countries, in his view, was to acquire "latent" nuclear capability:

> You don't really even need to have a nuclear weapon…It's enough to buy yourself an insurance policy by developing the capability, and then sit on it. Let's not kid ourselves: Ninety percent of it [the new interest in nuclear power in developing countries] is insurance, a deterrence.[79]

For the United States to resume the pursuit of commercial reprocessing could have the gravest of proliferation consequences both in terms of its example and in terms of the development of new technology. While restraint on the part of the United States in this regard may not halt reprocessing development in other countries, it is much more likely that its pursuit in the United States will encourage it elsewhere.

F. Breeder reactors

As we have seen, it is essentially impossible to use a large fraction of the underlying uranium resource for energy production without breeder reactors. Sodium-cooled fast breeder reactors (called "fast" because fission is accomplished with high-energy or "fast" neutrons) have been the

[78] Qusti 2006
[79] As quoted in Warrick 2008

ones most sought after because they have the best breeding ratio, which is the ratio of fuel produced to that consumed. In a breeder reactor, this ratio is more than one.

In a breeder reactor, depleted uranium, which is the byproduct of uranium enrichment, is put in a "blanket" around the breeder reactor core and converted into plutonium. This conversion is not part of the generation of energy from fission, which occurs in the central part of the core from MOX fuel containing a much higher percentage of plutonium than light water reactor MOX fuel. Rather the outer part of the reactor, the "blanket," is dedicated to the purpose of converting uranium-238 into plutonium. This plutonium would be greater in quantity than that consumed in the core, resulting in a net increase in fuel, and providing the theoretical possibility of using up almost all the uranium resource.

The development and commercialization of breeder reactors, which has focused worldwide on sodium-cooled fast reactors, has been a failure, despite immense effort and expenditure. Table 3 shows the demonstration breeder reactors that have been built so far (pilot plants of less than 100 megawatts electrical are omitted). Looking at the overall record of nearly six decades of experience, there is no evidence of a significant learning curve. Some demonstration reactors have operated well; some have not.

If there were, a positive learning curve would show that the early plants functioned worse than the later ones. But this is not the case. Some early plants worked well; other did not. The same is true of the more recent ones. The first small sodium-cooled reactor, the EBR I built at the Idaho National Laboratory, had a partial meltdown. The second one built at Idaho, EBR II, operated well; its proponents wanted it to be the reactor component in an IFR scheme to be developed at INL. But the first breeder built as a commercial power plant, Fermi I near Detroit, ran into problems early on and never generated much energy. And so on, up and down it has gone over six decades.

The two most recent large demonstration reactors to be completed – Superphénix in France (by far the largest breeder reactor ever built) and Monju in Japan have among the worst performance records. Superphénix had a lifetime capacity factor of under 8 percent from grid connection in 1986 to shut down at the end of 1996 and did not operate at more than one-third capacity factor in any of those years.[80] Monju had a secondary sodium loop fire about a year-and-a-half after commissioning and remained shut as of early March 2010. Efforts are being made to repair and restart it. The restart date has been repeatedly postponed and was recently scheduled for late March 2010.[81] But it did not restart by then.

[80] IAEA Super-Phénix 2009
[81] Nuclear Engineering International 2010

Table 3: **Capital Costs of Breeder Reactors Larger Than 100 megawatts-thermal (MWt)** (Note 1)

Name and country	Capacity MWt	Capacity, MWe - Net/Gross	Grid connection dates	Capital cost million US dollars, Constant 1996	Cost per kWe, 1996 US dollars	Comments
Fermi 1, USA	300	61/65	1966-1972	403	4,030	partial meltdown, scant operation
BN350, Kazakhstan	1,000	350 equivalent	1972-1999	724	2,172	massive sodium fire, 20 to 25 percent enriched uranium fuel; electricity plus desalination
Phénix, France	560	233/250	1973-2009	395	2,116	operated reasonably well
Dounreay PFR, Britain	600	234/250	1974-1994	395	1,975	many operational problems
BN600, Russia	1,470	560/600	1980-	918	1,873	designed for 20 to 25 percent enriched uranium fuel, 14 sodium fires
FFTF, USA	400	133	1980-1993	1,397	10,478	operated reasonably well
Superphénix, France	2,900	1,200/1,242	1986-1998	6,028	4,822	operated at 7 percent average capacity factor, many operational problems
Monju, Japan	714	246/280	1995	5,134	21,571	secondary sodium fire led to closure; not yet reopened; current date for start of tests after end of March 2010; three years of tests to follow
SNR-300, Kalkar, Germany	762	254	Did not open	4,272	16,819	safety concerns led to decision not to operate
Total	**8,906**			**19,666**	**7,317**	

Notes: 1. Adapted from Makhijani 2001 Table 3 (pp. 22-23). This table consists of large sodium-cooled reactors that could be used as breeder reactors in theory, whether or not they were actually used as breeder reactors. For details of how estimates were made, including conversion from local currency to US dollars and adjustment from current to constant dollars, see Makhijani 2001 Table 3. Pilot plants not shown; demonstration reactors only ~100 MW electrical or more.

2. **Operating, fuel, maintenance, and decommissioning costs are not included.**

Sources: Makhijani 2001 Table 3 and the following: Phénix closing date: CEA 2009. Electric capacities from IAEA 2006, except and FFTF and SNR-300 are IEER calculations. For comments: Fermi 1: Fuller 1976 and IAEA

Fermi 2009; BN350 and BN600: IPFM 2010; Phénix: IAEA Phénix 2009; Dounreay: IAEA Dounreay 2009 and Cruickshank and Judd 2000; FFTF: Cadwallader and Petti 1999; Superphénix: IAEA Super-Phénix 2009; Monju: Miyakawa et al. 2000 and Nuclear Engineering International 2010; Kalkar: No Nukes Inforesource no date. BN350 and BN 600, IPFM 2010 p.64 and Albright, Berkhout, and Walker 1997, pp. 204-205. For sodium fires see IPFM 2010.

One problem is that liquid sodium, which is used as a coolant in all the breeder reactors, shown in Table 3, is a difficult and dangerous material. It burns on contact with air (which is what happened at Monju) and explodes on contact with water. Performance and operational requirements are very exacting. A review of sodium-cooled reactor problems in the excellent history of breeder reactors recently published by the International Panel on Fissile Materials indicates that, despite the advantage that sodium-cooled reactors can operate at low pressures, small and large problems with sodium cooling have been a common theme.[82] Because it is necessary to keep the sodium out of contact with air and water, it is typically much more complex and difficult to fix problems with sodium-cooled reactors than with light water reactors.

It is instructive to take a brief look at the two most recent demonstration breeder reactors, the Superphénix and Monju.

A French Parliament report on Superphénix[83] noted that it was not the nuclear aspect of the reactor but the sodium that had been at the center of the problems. In fact, the problems, catalogued in the report caused 25 months of shutdown of the reactor.[84] It was commissioned in January 1986. The major sodium-related shutdown incidents were as follows:

- 1987: poor choice of steel caused a tank to fail and a sodium leak. The shutdown and repairs lasted 10 months.
- 1990: the primary sodium circuit became contaminated with air due to a compressor malfunction. Sodium purification took eight months, during which the reactor was shut.
- 1994: an argon gas leak into a sodium-sodium heat exchanger inside the reactor vessel cause a seven-month shut down.

The Japanese demonstration breeder was commissioned at about the time of the last Superphénix sodium leak in 1994. In December 1995 it suffered a sodium fire in the secondary cooling loop. It remains shut (as of March 2010), despite long efforts to reopen it. Even after it is restarted, it will have to be tested again – currently three years of tests are envisioned.[85] So even if it is restarted this year, the Monju reactor will have generated essentially no electricity for its first 19 years, including, reportedly, the three years of forthcoming tests.

In sum, the most recent large demonstration reactors have not done better than the early ones; indeed their performance has been worse than some early ones. The history of sodium-cooled reactors gives no realistic basis for inferring a learning curve or for the optimism expressed by proponents that the problems can be overcome systematically and at reasonable cost. For

[82] IPFM 2010
[83] France. Assemblée Nationale 1998 Section II.A.3 (Des difficultés réelles de mise au point de l'installation mais aussi de son statut administrative)
[84] For comparison, the reactor fed electricity into the grid for only 53 months.
[85] Nuclear Engineering International 2010

instance, an assessment of the IFR by the University of California (Berkeley), Department of Nuclear Engineering[86] reads more like a promotional brochure than a serious assessment, such as the one produced in early 2010 by the International Panel on Fissile Materials.

It should be noted that Japan now expects to commercialize sodium-cooled reactors in the year 2050, about 80 years after the initial expected date, and about 100 years after the first sodium-cooled reactor was turned on in Idaho (EBR I, in 1951).[87]

There is also the issue of cost. No large breeder reactor has been built in the last 15 years (two are is under construction, one in India and one in Russia). It is difficult to estimate breeder reactor power production costs because they are not yet commercial This can be seen both from the large variation in operating time and in cost per kW of the demonstration breeder reactors in Table 3. Nuclear costs have escalated greatly in the last decade. Breeder reactor costs are expected to be higher even in the case of commercialization:

> Since breeder reactors were never built in quantity, it could be expected that, in production, this cost ratio would decline. Few if any argue today, however, that the capital costs for breeder reactors could be less than 25 percent higher than for water-cooled reactors of similar generating capacities. This would be a capital cost difference on the order of $1000 per kilowatt of generating capacity. At a 10 percent capital charge and a 90 percent average capacity factor, this would translate to a cost difference of about 1.3 cents per kilowatt hour.[88]

According to the report of the International Panel on Fissile Materials, governments belonging to the Organization for Economic Cooperation and Development (commonly referred to as the "West," including Japan) have reported spending $50 billion on breeders since 1974, but that this does not include most of the cost of the Superphénix. In addition, about $12 billion of Russian expenditures are not-included.[89] When expenditures before 1974 and in other countries like India are taken into account, $100 billion (2007 dollars) is a reasonable approximate estimate of breeder reactor development costs to date.[90] This does not include future costs of decommissioning.

In addition, tens of billions of dollars have been spent on reprocessing costs in plants that were originally conceived to support breeder reactor programs. They have no economic rationale and practically no resource rationale in a light water reactor system.[91] .

In all, roughly $200 billion (2007 dollars) is a reasonable range of costs to date to commercialize a plutonium economy; including breeder reactor and reprocessing costs. The system is still far

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[86] Berkeley Nuclear no date.
[87] Green Action 2009, Mitsubishi 2007, and Albright, Berkhout, and Walker 1997 p. 196
[88] IPFM 2010 p. 7
[89] IPFM 2010 pp. 6-7
[90] Frank von Hippel, personal communication April 5, 2010
[91] See Makhijani 2001 for a discussion of some of the excess costs of reprocessing, especially pages 26-28, including footnotes. Up 1999, a partial count of excess commercial reprocessing costs were ~$60 billion in 1999 dollars or about $70 billion (rounded) in 2007 dollars. There have been more excess expenses since then.

from commercial; an essential element, the sodium-cooled fast breeder reactor, is not even technologically developed enough to be consistently reliable.

G. Reprocessing and spent fuel stocks from existing U.S. reactors

As we have seen, statements that 90 or 95 percent of the material in spent fuel can be used are completely invalid without breeder reactors. In this section we will examine some of the implications of a policy that seeks to deal with existing spent fuel by trying to convert the mass of the material into fuel and using it for energy, assuming that breeder reactors will work and can be deployed on a large scale.

We start with a heuristic calculation. A 1,000-megawatt nuclear power reactor fissions about one metric ton of heavy metal per year in the course of energy generation. At present, there are over 60,000 metric tons of spent fuel in the United States. With reactor re-licensing, the total amount of spent fuel could amount to well over 100,000 metric tons by the time the reactors are retired; 95-plus percent of the content of this spent fuel is uranium or transuranic elements (mainly plutonium). We will use a round number of 100,000 metric tons[92] of uranium and plutonium content in spent fuel that would be converted into fuel. This corresponds approximately to statements that 90 or 95 percent of existing spent fuel has "energy value" and hence should not be regarded as waste. For instance, such a scheme would appear to be the one that Dr. Miller had in mind and that NRC Commissioner Bill Magwood made explicit in his discussions of spent fuel management.[93]

Setting aside for the moment a variety of difficult issues, including those associated with the rate of conversion of uranium-238 into plutonium, it is easy to see that it would take 100,000 reactor years (assuming 1,000 megawatt reactors) to convert the heavy metal content of spent fuel from the existing fleet of U.S. power reactors into fission products in a manner that extracts essentially all the physically possible energy value in it.

Assume a reactor operating life of 50 years, accumulating 100,000 reactor years would mean building 2,000 reactors to extract the energy in the total spent fuel from the existing fleet of reactors. This is about 20 times the size of the existing U.S. nuclear power system. It is four times the total electricity generation of the United States and seven or eight times the baseload requirements under the present centralized electricity dispatch system. If the material is consumed in a smaller number of reactors, the time to consume it would be proportionally increased. For instance, it would take 200 years to consume the material in 500 reactors.

The matter gets more complex when the time required to breed plutonium out of uranium-238 is taken into account. This is because it takes considerable time to build up the inventory of plutonium created from uranium-238 in breeder reactors to get to the point where all reactors

[92] The estimates in this section are rounded to one significant figure and are order of magnitude values provided as heuristic calculations to illustrate the magnitude of the problem of converting most or all of the uranium in spent fuel to fuel.
[93] Miller 2009 and Magwood and Ribbing 2009

would be fueled with plutonium alone (mixed with depleted uranium). In the meantime a considerable amount of the fissile material requirements would consist of enriched uranium fuel. This would increase the uranium fuel requirements, in turn increasing the amount of uranium-238 to be converted into plutonium. In other words, the number of reactor-years needed to make substantially complete use of the uranium resource in existing spent fuel would be even greater than indicated by the above calculations.

Along the way the process will involve separating on the order of 100 million kilograms of plutonium, enough for more than ten million nuclear bombs. Even if it is mixed with some other materials that make making a nuclear weapon more complex, the material is usable in nuclear weapons. Worldwide, the total material that would be converted in such a process to fuel would be about three times the amounts in the United States[94] or enough for more than 30 million nuclear bombs.

These considerations lead to some basic technical and proliferation-related conclusions about a system in which 90 to 95 percent of the "energy value" of the materials in existing spent fuel is to be extracted:

- Large amounts of spent fuel will have to be stored for very long periods, extending in some cases to hundreds of years (instead of being disposed of in a repository) awaiting reprocessing.
- The process will involve making on the order of 100 million kilograms of plutonium – enough to make more than 10 million nuclear bombs from U.S. material alone.
- If the United States is able to widely deploy reprocessing and breeder reactor technologies, other countries are likely to do it as well (see below). More than 30 million nuclear-bomb-equivalent fissile materials are at issue worldwide from spent fuel from existing reactors alone.
- If the conversion of non-fissile uranium in spent fuel from existing reactors to fissile materials is carried out over say 300 years, the amount of weapon-usable material separated each year in the United States will be enough to make more than 30,000 bombs, about equal to the peak of the U.S. nuclear arsenal of the United States during the Cold War. The corresponding figure for worldwide separation will be roughly 100,000 nuclear bombs annually. It is highly questionable whether safeguarding or even accounting for so much material is a reasonable proposition.

It is impossible to determine either the costs or security consequences of a system in which so much separated fissile material is being separated each year.[95] But we can infer some things from past experience. There is, of course, the well-known case of North Korean proliferation using plutonium separated from spent fuel from a power producing reactor. But there have been

[94] This is an approximate value based on a U.S. generation fraction of about a third (31 percent of worldwide nuclear generation of electricity in 2008 – see NRC 2009-2010 p. 24). In practice the details will be different. For instance, some reactors designs, like the Canadian heavy water reactor design, CANDU, use natural rather than enriched uranium, which take a larger total uranium loading.

[95] It should be noted that while proposals for the IFR in the United States are usually in the context of a co-located reactor and reprocessing plant, co-location is not inherent in the technology. Countries may choose, for a variety of reasons, including economic, to build centralized electrometallurgical separation facilities. See Wymer et al. 1992.

issues even in the OECD countries. For instance, it took 15 years of official investigations of a Japanese plutonium discrepancy of over 200 kilograms – sufficient for about 30 nuclear bombs – at relatively small reprocessing plant in Tokai-mura. The government and the IAEA concluded that none had been diverted. Half of it was apparently never produced. The shortfall in production was apparently not detected at the time of production but had to be retrospectively investigated. Most of the rest had been discarded as waste, the investigation concluded. The Japanese discrepancy involved about 3 percent of the total plutonium separated at the plant.[96]

An example from the military sector is also instructive, since it provides one more illustration of keeping track of fissile material, especially in nuclear waste generated during material processing. Los Alamos National Laboratory, arguably the crown jewel of U.S. nuclear weapons research establishment, has two sets of numbers for plutonium in waste that do not match, one maintained by Department of Energy headquarters and the other by waste management at the site and the Environmental Protection Agency. According to an IEER report, the discrepancy amounts to about 300 kilograms of weapon-grade plutonium – enough for about 60 nuclear bombs. Each agency maintains that its account is correct. But IEER has pointed out that both numbers for the same thing cannot be right, though they might both be wrong. And there the matter has stood since 2006.[97] While the cumulative amount of plutonium handled at Los Alamos is not publicly known, the discrepancy is likely to be on the order of 1 percent or more, given that most plutonium was processed into weapons at Rocky Flats in Colorado and the total plutonium production in the U.S. weapons complex was about 100 metric tons.[98]

Based on these examples, discrepancies of hundreds of kilograms in a world in which annual separations, both commercial and military, have averaged on the order of 10,000 kilograms of plutonium, one can infer that inspections and verification infrastructure would have to be 100 times more effective to maintain a level of materials accounting that has never been entirely satisfactory from a proliferation standpoint, assuming the approach being advocated is implemented worldwide. Whether this can be done technically, how much it would cost, and whether it is politically feasible given current proliferation trends has not even begun to be seriously discussed.

Then there is the matter of economics. To implement the scheme of converting much or most of the material in spent fuel to usable fuel is not within economic reach at present:

- The use of MOX fuel made from reprocessed plutonium costs about two cents per kWh more than that from uranium fuel at the best operated plant in the world – that in France. In other places the numbers are even more grim.
- Breeder reactors today cost much more than light water reactors.

At the present state of development of reprocessing and breeder reactors the additional costs of converting uranium-238 recovered from spent fuel in breeder reactors into plutonium-238 would cost several cents more per kWh than once-through uranium fuel use.

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[96] Hall 2003

[97] Makhijani and Smith 2006. In addition to this report, IEER's correspondence with federal government agencies and their responses can be found at http://www.ieer.org/pu/index.html.

[98] Total U.S. military plutonium production was disclosed in an official report in 1996. See DOE 1996.

To illustrate the utter impracticality of using this approach with anything like the present cost structure, consider the case where the added cost of electricity generation is only one cent per kWh compared to available alternatives. Since about each 1,000 MW reactor generates about 8 billion kWh per year, 100,000 reactor years would have a cumulative generation of 800 trillion kWh. For each penny per kWh added cost, the total additional cost (undiscounted constant dollars) would be $8 trillion. This far exceeds the total value of electricity that has been and will be generated by the present fleet of reactors.[99]

It is immediately evident that the scheme is economically impractical even if all proliferation and technical problems and associated costs) associated with large scale reprocessing and breeder reactors are ignored.

It should be noted that the cost of the breeder-reprocessing system will have to be brought down not only to the level of light water reactors without reprocessing, but to alternative renewable electricity sources. At present light water reactors are already generally more expensive than wind-generated electricity, even when compressed air energy storage is added to make wind energy available even when the wind does not blow.[100]

In addition, solar technologies are maturing. Concentrating solar thermal power is broadly comparable in cost to light water reactors; solar photovoltaics are somewhat more expensive today. The costs of both are expected to decline rapidly in this decade. It is likely that both will be comparable to wind in that time.[101]

Overall, reprocessing plus breeders has a huge economic hurdle relative to light water reactor technology. Breeder reactors are not highly likely to be commercially competitive with renewable energy technologies even if the technological problems that have afflicted them are overcome.

Further, if one of the goals is to transmute long-lived fission products, minor actinides like neptunium-237 and americium-241, and long-long-lived activation products into stable or short lived elements, the approach will become even more expensive.[102]

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[99] We assume each 1,000 MW reactor operates at a little over 90 percent capacity factor. The existing fleet of 104 reactors generates about 800 billion kWh per year (rounded). At 5 cents per kWh wholesale at the busbar (generating station dispatch point), the annual value of electricity generated is $40 billion. This adds up to $2.4 trillion over 60 years, assuming license extensions of 20 years for all reactors now operating.

[100] It is difficult to estimate unsubsidized costs of nuclear energy in the United States at present, since Wall Street refuses to finance the plants as too risky. The California Energy Commission puts the costs of a plant coming on line in 2018 between about 17 and 34 cents per kWh (rounded), depending on plant ownership and financing compared to costs for wind-generated electricity (land-based) from 8 to 13 cents per kWh, depending on ownership structure and wind speeds at the site. See California Energy Commission 2009, Table 5, p. 18. Compressed air energy storage (CAES) would cost another 3 cents or so per kWh, making the total for dispatchable wind 11 to 16 cents per kWh. Author's estimate of CAES cost based on configuration for baseload wind by the National Renewable Energy Laboratory. (NREL 2006). The estimates of the author of this paper for electricity from unsubsidized new light water reactors are 12 to over 20 cents, if there are no delays or significant real cost escalations over the construction period.

[101] California Energy Commission 2009 p. 6 and p. 18

[102] Various transmutation technologies are discussed in Zerriffi and Makhijani 2000.

If a penny per kilowatt-hour penalty presents an insuperable hurdle to the management of existing spent fuel using reprocessing and breeders, is it even worth contemplating?

Advocating a reprocessing-breeder reactor system to extract 90 or 95 percent of the energy value in spent fuel from existing reactors does not add up to a sound policy direction from the logistical, security, or cost point of view. Given the vast amounts of fission and activation products as well as large amounts of Greater than Class C waste, sizeable repository disposal capacity will be needed even after storing the spent fuel for prolonged periods – likely to extend to hundreds of years in some cases.

A detailed consideration of the facts shows that slogans and romantic appeals to “energy value” of the resource in spent fuel and to France, such as the ones by Dr. Miller and Commissioner Magwood cited at the beginning of this report have become a parallel to the unrealistic and technically ill-founded promise of nuclear power “too cheap to meter” of the 1950s.

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Reprocessing Nuclear Waste

By
Bruce Breslow
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Yucca Mountain as an Interim Storage and Reprocessing site?

- First, it's against state law
- Second, the nation tried and failed at reprocessing
- Reprocessing produces weapons grade plutonium as a byproduct
- Nasty liquid waste stream
- Cost of cleanup for past reprocessing at Hanford, WA - $205 to $260 Billion

Reprocessing in France and England

- 100 million gallons of liquid waste annually into the sea
- Must store weapons grade plutonium on site in Normandy with extraordinary security
- The process must be government subsidized

NWTRB Reprocessing Meeting in Maryland

- All 3 companies said they can reduce the Volume of high-level waste by a factor of 4, but the OVERALL volume of waste actually increases by 6 times
- Less high level waste - but now in a nasty liquid form
- Literally tons more mixed waste, transuranic waste and low level waste
- Can't meet EPA standards for Krypton gas, Iodine 129 and Tritium
- A large reprocessing facility would need approximately 78 thousand acre feet of water annually - There is none at Yucca Mountain
- All 3 firms said they'd still need a permanent deep geologic repository for high level waste
- All 3 firms said they'd need the money in the nuclear waste fund to pay for the costs of reprocessing
- Of course, if they use the money for reprocessing there won't be any for a $96 Billion dollar repository somewhere.
- No one offered a financial model that works - reprocessed fuel is at least 6 times more expensive then new uranium fuel which is cheap and plentiful.

Billions for the State?

- There is no money
- Nothing offered to Nevada the last 27 years
- The Nuclear Waste Policy Act - $10 million per year until waste received at Yucca Mountain, then $20 million annually after, but only if NV gave up its rights
- No national laboratory
- No improvements for transportation or infrastructure

How many of you would want to locate your headquarters next to the nation’s nuclear waste dump?

The Question of reprocessing nuclear waste at Yucca Mountain

Some people have suggested that Yucca Mountain should be used as an interim storage site for reprocessing the nation's spent nuclear fuel and high level waste, as well as a permanent deep geologic disposal site.

It is currently against federal law(Nuclear Waste Policy Act) for Nevada to be an interim storage site while still designated in the Act for a permanent repository. Our nation tried, and made quite a mess of reprocessing at Hanford, Savannah River and West Valley, New York. Reprocessing creates a bi-product of weapons ready plutonium and changes the solid waste into a much nastier liquid waste stream. Currently the Department of Energy estimates the cost of cleaning up the reprocessed leftovers in Hanford, Washington to be $260 Billion Dollars. Savannah River is still cleaning up from reprocessing and the site in West Valley cost the nation billions to reclaim.

France and England reprocess and in doing so they pump millions of gallons of liquid radioactive waste annually into the sea as part of that process. They are being sued by Ireland over the radioactive discharge. They also store reprocessed weapons-grade plutonium on site with anti-aircraft batteries next to the plant in Normandy. The process is heavily subsidized by their governments and produces fuel that is 6 times more expensive then new fuel which is cheap and plentiful.

At a 2009 U.S. Nuclear Waste Technical Review Board meeting in Maryland the topic was "Closing the Nuclear Fuel Cycle." The top 3 reprocessing firms in the world; AREVA, Energy Solutions and GE-Hitachi were invited to explain what they could do in the U.S. After their presentations one thing was clear, no one has the technology to close the fuel cycle and eliminate the waste.

All 3 companies said they think they can reduce the Volume of high level waste by a factor of 4. But the OVERALL volume of waste actually increases by 4 to 6 times. Less high level waste which is now in a liquid form, but literally tons more mixed waste, transuranic waste and low level waste. Unlike in Europe, we do not allow pumping the liquid waste into the ocean. Those firms also will have problems meeting EPA standards for Krypton gas, Iodine 129 and Tritium.

The process is highly water intensive and would require a nuclear power plant. The Yucca Mtn. area does not have <u>any</u> unallocated groundwater left, especially the 35,000 to 50,000 acre feet of water needed for a large fast breeder reactor for reprocessing. The Nevada State Engineer reports that the five water basins around Yucca Mountain are already over-appropriated. In addition, the chances of licensing a nuclear plant in a very high earthquake zone are slim. And, All 3 firms said they would <u>still</u> need a permanent deep geologic repository for high level waste even if they were to reprocess.

The firms said they would need ratepayers or taxpayers to pay for the multi-billion dollars required to reprocess unless they use the money in the nuclear waste fund to pay for the costs of reprocessing. (Of course, if they use the money for reprocessing there won't be any for a $96 Billion dollar repository somewhere.)

No one offered a financial model that is acceptable to the U.S. financial markets, let alone their own boards. The US nuclear industry stated it is "against paying one more dime for reprocessed fuel," that is 6 times more expensive than new uranium fuel which is cheap and plentiful.

As for the billions of dollars that might flow into the State? No one has offered Nevada anything in the last 27 years. There is no money outside of what's in the 1987 Nuclear Waste Policy Act. Nevada could sign an agreement to accept $10 Million for "mitigation" until the waste is in the mountain, and $20 Million a year thereafter if we were willing to give up our independent oversight role and legal rights established by the Act. No general fund dollars. No national laboratory. No improvement to our transportation infrastructure.

In summary, reprocessing would eat up vast quantities of water, require the licensing and construction of a large nuclear reactor, still require a full size repository, and is not being promoted by its own industry because of the costs.

Our nation currently does not reprocess commercial fuel and another big reason is that it creates a bi-product of weapons ready plutonium. Reprocessing is how the US, Russia, India, China and others created their nuclear weapons programs. It is difficult for the United States to tell the 15 to 20 nations who want to start a nuclear program not to reprocess, if the US begins doing it again itself.

Scientists predict that they will come up with new and much better techniques to re-use spent nuclear fuel and nuclear waste in the next 20 to 50 years. The President's Blue Ribbon Commission on the Nation's Nuclear Future is looking at new technology and making a recommendation within 12 months about what to do with the country's stockpile of used fuel and waste. The NRC has stated that keep the fuel at reactor sites in dry cask storage is safe for another 50 years and they are looking at increasing that to a much longer period. America may indeed look at reprocessing again in the future, but certainly at an area with a plentiful water supply and suitable land to site a new kind of nuclear reactor. That site is not, and cannot be, Yucca Mountain.

YUCCA MOUNTAIN – LESSONS TO BE LEARNED AND A STRATEGY FOR THE FUTURE

Presented By: Bruce Breslow, Executive Director,
State of Nevada, Agency for Nuclear Projects

Part 1 – What Went Wrong?

The U.S. Department of Energy was probably the wrong entity to implement the federal high-level radioactive waste program and placing the program within DOE may have doomed it from the start.

- The original Nuclear Waste Policy Act of 1982 was a complex piece of legislation that sought to balance numerous competing interests and constituencies. The very character of DOE, with its culture of secrecy, its 'we know best' decision-making, its schedule-driven approach, and its inability to work in a cooperative manner with states and communities, made it the worst possible entity to implement a program that required the level of sophistication needed to effectuate the difficult compromises embodied in the Act.
- In Nevada, DOE created a hostile atmosphere almost from the beginning by trying to interfere with the state's Yucca Mountain oversight program, and insisting on approving all activities the state proposed to implement. As early as 1984, the State was forced to go to court to secure its independent oversight role. The court strongly admonished DOE, finding that allowing DOE to approve or disapprove the state's specific oversight work would be akin to "permitting the fox to guard the chicken coop."
- Even after the court ruling, DOE continued to interfere with Nevada's oversight by withholding, delaying and otherwise impeding needed funds, hampering site access, and making it difficult for Nevada personnel to gain access to needed data and information.
- The Alternative Means of Financing and Managing (AMFM) Panel[1] as early as 1984 recommended that the high-level waste management program be removed from DOE and set up as a quasi-governmental corporation to insulate it from political influences and to

[1] Section 303 of the Nuclear Waste Policy Act of 1982 required the Secretary of Energy "to undertake a study with respect to alternative approaches to managing the construction and operation of all civilian radioactive waste management facilities, including the feasibility of establishing a private corporation for such purposes." The section was in response to concerns, even as early as 1982 and before, that housing the waste program in a federal agency would doom it to failure due to the undue influence of politics and the vagaries of changing administrations. The AMFM Panel released its report, "Managing Nuclear Waste – A Better Idea," in December 1984 which concluded that "[t]he Panel's preferred long-term alternative to the Office of Civilian Radioactive Waste Management (OCRWM) for managing the nation's high-level radioactive waste program is a public corporation chartered by Congress."

provide the program with stability and continuity over the long period of time that would be required to site, construct and operate one or more repositories.

- Because of the heavy-handed manner in which DOE has implemented the Yucca Mountain program and the history of instability in leadership, mismanagement, faulty science and data irregularities, and a host of other serious problems over the years, it would be next to impossible for a similar siting program implemented by DOE to obtain the level of trust and confidence necessary for a successful program.

The Nuclear Waste Policy Act, as amended in 1987, created an adversarial role between DOE and the State of Nevada.

- The amended NWPA stated that: "The State or Indian tribe that is party to such agreement waives its rights under Title I to disapprove the recommendation of a site for a repository." Several Nevada Attorneys General opined that Nevada would forfeit its rights to participate in critical safety and environmental issues during NRC licensing if it even began to negotiate with DOE on a limited benefits package offered by the NWPA.
- Even if Yucca Mountain had turned out to be a suitable site (which it did not), Nevada was offered only $10 million a year after license approval and $20 million a year once waste was shipped to Yucca Mountain. That wouldn't even cover the cost of escorting and overseeing the shipments through the State.

Early on, it was known that the Yucca Mountain site had serious geotechnical problems, but DOE ignored or trivialized them and proceeded as if its mandate was to do whatever it took to make Yucca work.

- The focus of DOE's work on the project changed after the 1987 amendments to the Nuclear Waste Policy Act singled out Yucca Mountain as the sole site for characterization. DOE went from asking, "Is Yucca a suitable site?" to "What do we need to do to make the site work?" And that quickly evolved to, "What regulations and standards have to be changed?" and "How do we engineer the facility so as to try to overcome the site's physical flaws?" This led to a series of ever-more-exotic engineering "fixes." For example, the current license application includes covering all the waste canisters with 11,500 titanium drip shields to protect them from rock fall and highly corrosive groundwater. But the $10 to 12 Billion needed for the drip shields is not part of the budget, and the drip shields themselves are only proposed to be installed 80 to 100 years AFTER the waste is put into the mountain. And since the site is physically and radiologically too hot for humans, robots would have to install the shields inside of the tunnels with no margin for error.
- The "science" at Yucca deteriorated as time went on and more and more unfavorable findings surfaced. DOE's site characterization program appeared to be designed NOT to identify anything that might disqualify the site.

- Despite this, potentially disqualifying conditions were revealed at the site (i.e., fast groundwater pathways, unacceptably high level potential for escaping radioactive gasses, recent volcanism, high levels of seismicity, etc.). **To get around this, DOE petitioned Congress to exempt the site from health and safety regulations and then scrapped its own site evaluation guidelines altogether.**
- The fact that Yucca was an unsuitable and unsafe site made it impossible for the State to even consider cooperating with DOE.

Yucca Mountain failed for a lot of reasons, but a critical element was unquestionably the forced nature of the siting process – i.e., Congress directed that Yucca Mountain be the only site to be studied; DOE used that directive as the basis for pushing ahead with the project even when the data showed serious flaws in the site and in the face of strong and determined opposition from the state.

- If DOE had been required to obtain the State's informed consent to continue with the project, Yucca would have been disqualified years earlier (saving billions of dollars and years of effort) and DOE would have had to move on to identify a truly suitable location.
- The notice of disapproval contained in the Nuclear Waste Policy Act was essentially meaningless, because the bar was (intentionally) set so high that a small state like Nevada could not be expected to obtain two-thirds of the votes in both the House and Senate needed to sustain the State's veto in the face of an administration determined to force the site on the State and a Congress anxious not to risk exposing members' states to a new siting effort.
- There was no incentive for DOE to work with or listen to the State, since DOE believed all along that it would be able to force the decision on Nevada, regardless of concerns about the site.

Congress shares a large portion of the blame for the failure of the federal high-level radioactive waste program to produce a repository.

- The original Nuclear Waste Policy Act of 1982 was a complex and cumbersome law that sought to balance a variety of competing and often conflicting interests. But the Act represented significant agreement on the part of diverse affected parties and might have had a chance of succeeding, if politics had not intervened in 1986 and if Congress had

held DOE's feet to the fire, (requiring DOE to implement the original Act as intended,) and had not gutted the Act in response to political considerations in 1987.[2]

- While a repository (or other nuclear facility) siting process cannot realistically be insulated from politics completely, there are things that can and must be done to minimize political influence and increase the likelihood that a sound, scientifically-based and credible process can go forward.

Part 2- The Future

How can the federal government successfully site and build a deep geologic repository(s) in the future?

- Let me preface these remarks by saying that my observations are based on Nevada's experience with the failed Yucca Mountain project. Nothing in the remarks should be construed as suggesting in any way that the Yucca Mountain site can somehow be fixed or made acceptable to the State of Nevada. I am merely using our experience to suggest some key findings with regard to how a future siting process might benefit from Yucca's failure.

- In thirty years, no State has come forward and offered to host a HLW repository. There's a big risk that immediately makes the public skeptical from the outset, and energizes the anti-nuclear groups around the country. States are currently suing to keep DOE from withdrawing the Yucca Mountain License, citing that their State might be considered if Yucca is cancelled. In fact, there may be a need for a cooling off period of 5 to 10 years to effectively recalibrate the effort.

The final decision must be voluntary

- A successful siting effort must begin with a clean slate, looking for the best sites science can find. No State or physical medium should be exempt from the scientific search. However, the final "choice" or choices must be fully voluntary. Without the opportunity to say NO, a State will have a hard time engaging in any conversation. Sites should be

[2] During the election cycle of 1986, the Reagan Administration, responding to political pressure from eastern states that had potential sites being examined for a second repository, directed DOE to suspend the second repository program (an important component in the Act to insure regional equity). In 1987, powerful states with potential first repository sites (esp. Louisiana, Texas and Washington) successfully managed to gut the carefully crafted selection process for the first repository, get their states off the hook and single out Nevada's Yucca Mountain based on political considerations [i.e., Nevada's political weakness vs. the clout of Senate Energy Committee Chairman J. Bennett Johnston (LA), House Speaker Jim Wright (TX) and House Majority Leader Tom Foley (WA)].

thoroughly characterized first, prior to being selected. No state should be allowed to opt out of the initial site search.

There must be credibility developed on the local, regional and State level.

- A full partnership must be part of the structure with the State, Tribe, County and local entity. This means being a full partner with DOE or whatever entity is identified to implement the effort to develop a credible repository program. It's typical that a voluntary local entity will want the high paying jobs, while the County will have to provide regional services and the State will have to maintain the proper transportation infrastructure, scientific oversight, escorts and safety inspections. All of these entities should work together in a full partnership where every study, report, decision, and plan is fully transparent. With comprehensive "buy-in" from all appropriate sectors, when problems are found, they are everyone's to resolve. If safety concerns cannot be alleviated, then the State must have the final decision to opt out. Without this, no state will be willing to go down the road on a repository project.

- Once there is a commitment to a scientifically-based and truly voluntary siting process, the entity responsible for the program might then be able to build credibility by offering meaningful incentives for hosting a facility. Such an inducement might include establishing prestigious nuclear energy research facilities near the site including a new national laboratory. It would be viewed as a risk/reward for the local community by bringing experts to the State and locality and making them part of the site, project, and community. As these prestigious scientists and experts become part of the local fiber of the community, they bring their credibility to the area and eventually the project, in effect, calming the nerves of all involved. But this can only work if the site is scientifically suitable and the participation of the host state is voluntary.

There must be compensation

- A State must also be financially compensated for hosting a repository. However, the amount of compensation must be substantial enough for a state to consider it a true incentive. The Nuclear Waste Policy Act contained an essentially meaningless provision for benefits in the amount of $10 Million dollars per year ($20 Million after receipt of waste) with the caveat that the state must give up all safety and licensing participation for the funding. A State cannot give up its rights to ensure safety and provide appropriate oversight. For an incentive to be meaningful to even a small state, it would take compensation in the <u>billions</u> of dollars a year to even begin discussions. For a fraction of

a cent added to every nuclear produced kilowatt hour of electricity, the program would have the necessary funds to allow a State to not only help mitigate the risks, but provide for proper oversight and infrastructure improvements to accompany the project. These funds and the other substantial inducements must be set up contractually so they are not at the mercy of future national politics. Half of the funds should start after a site is licensed and then the rest of the funds should be paid once waste begins being transported to the site.

A repository cannot be a federal project. It must be a COMMUNITY project, run by DOE (or whatever entity is ultimately tasked with implementing the project), with its State, County and local partners.

A successful repository project can be achieved, but only if it's an open process fully involving the state, region and local communities. It's a risk/reward venture that everyone must share in developing.