Draft
Global Nuclear Energy Partnership Programmatic Environmental Impact Statement

DOE/EIS-0396

Summary

October 2008

U.S. Department of Energy, Office of Nuclear Energy

DOE/EIS-0396

Draft
Global Nuclear Energy Partnership Programmatic Environmental Impact Statement

Summary

October 2008

Prepared by:

SUMMARY

Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DUPIC	direct use of spent pressurized water reactor fuel in Canada Deuterium Uranium
EIA	Energy Information Administration
EIS	Environmental Impact Statement
FR	Federal Register
GNEP	Global Nuclear Energy Partnership
GWe	gigawatt-electric
LCF	Latent Cancer Fatality
MOX	Mixed-oxide
MOX-TRU	Mixed-oxide fuel made up of uranium and transuranics
MOX-U-Pu	Mixed-oxide fuel in which pure plutonium is not separated out from the uranium
MTHM	Metric Tons Heavy Metal
PEIS	Programmatic Environmental Impact Statement
PUREX	Plutonium and Uranium Recovery by Extraction
R&D	research and development
U.S.	United States

SUMMARY

S.1 INTRODUCTION

The Global Nuclear Energy Partnership (GNEP) Program, a United States (U.S.) Department of Energy (DOE) program, is intended to support a safe, secure, and sustainable expansion of nuclear energy, both domestically and internationally. Domestically, the GNEP Program would promote technologies that support economic, sustained production of nuclear-generated electricity, while reducing the impacts associated with spent nuclear fuel disposal and reducing proliferation risks. DOE envisions changing the U.S. **nuclear energy fuel cycle**[1] from an open (or once-through) fuel cycle—in which nuclear fuel is used in a power plant one time and the resulting **spent nuclear fuel** is stored for eventual disposal in a geologic repository—to a closed fuel cycle, in which spent nuclear fuel would be recycled to recover energy-bearing components for use in new nuclear fuel.

> **Nuclear Energy Fuel Cycle**
>
> A nuclear energy fuel cycle is the series of steps from mining to waste disposal involved in the production of electricity from nuclear fuel.

> **Spent Nuclear Fuel**
>
> Spent nuclear fuel consists of nuclear fuel that has been withdrawn from a nuclear reactor following irradiation. Typically, no more than five percent of the fuel has been used before the nuclear fuel is considered used, or "spent," and must be replaced with fresh fuel.

The *National Environmental Policy Act* (NEPA) requires that an Environmental Impact Statement (EIS) be prepared in order to inform the public and the decision-makers of the potential environmental impacts of proposed Federal actions and the reasonable alternatives prior to making any such decisions. For a broad program such as GNEP, which could involve many actions with far-reaching consequences over a long period of time, a program-level EIS (referred to as a Programmatic Environmental Impact Statement [PEIS]), is the appropriate document because it is relevant to policy-level decisions and is timed to coincide with meaningful points in agency planning and decision making (40 *Code of Federal Regulations* [CFR] Section 1502.4(b)).

This GNEP PEIS provides an analysis of the potential environmental impacts of expanding nuclear power in the U.S. using either the existing fuel cycle or various alternative closed and open fuel cycles. DOE's preference is to close the fuel cycle. The alternatives are described below in Section S.2.

In general, the analyses in this PEIS indicate that the closed fuel cycle alternatives offer a greater opportunity, relative to the open fuel cycle alternatives, to reduce the capacity requirements for a future geologic repository, and to reduce the hazards associated with the disposal of spent fuel or **high-level radioactive waste.** However, the closed fuel cycle alternatives require more disposal

> **High-Level Radioactive Waste**
>
> High-level radioactive waste is defined as: 1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and 2) other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

[1] Text boxes provide additional information on words that are bold-faced.

capacity for other radioactive wastes than is required under the open fuel cycle alternatives. Furthermore, transportation and associated health impacts from the closed fuel cycle alternatives would be generally higher during the operational period than those from the open fuel cycle alternatives (with one exception[2]). Potential environmental impacts are summarized in Section S.4.

The GNEP Program also has an international component (referred to as international initiatives) pursuant to which the U.S. would cooperate with other fuel cycle nations (i.e., those already recycling spent nuclear fuel) to develop and deploy advanced nuclear recycling and reactor technologies in those countries in order to move away from producing separated pure plutonium. Furthermore, the GNEP Program would work to put in place a framework for reliable nuclear fuel services in order to remove the need for a country to develop its own **enrichment** or **reprocessing** facilities. This PEIS identifies two international initiatives and discusses how these initiatives could produce environmental impacts within the U.S. and the global commons (defined as the environment outside the jurisdiction of any nation, such as the oceans or Antarctica). The analyses in the PEIS indicate that, in particular, the radiological dose to the public from the international component would be low in general, and would be somewhat greater under the closed fuel cycle alternatives than under the open fuel cycle alternatives (additional details are provided in Section S.6).

Enrichment—The process of increasing the proportion (or ratio) of uranium-235 atoms to uranium-238 atoms to make the mixture more usable as nuclear fuel.

Reprocessing—The process of separating the usable and unusable constituents of spent nuclear fuel.

Following completion of this PEIS, DOE will be in a position to decide whether to pursue a closed fuel cycle. This PEIS is a first, important step in deciding whether and how to recycle spent nuclear fuel. A decision to go forward with recycling could trigger additional proposals and research to achieve DOE's programmatic goal. Subsequent DOE policies and actions could also affect decisions by the U.S. commercial utility industry, which would ultimately determine whether and how to implement any changes in the domestic fuel cycle.

With regard to the international aspects of the GNEP Program, this PEIS does not evaluate any specific proposed actions or alternatives. Consequently, DOE would not make any decisions related to international initiatives and activities based on this PEIS.

At this time, DOE is not proposing project-specific or site-specific actions, such as the construction and operation of individual facilities to support the demonstration and deployment of any programmatic alternative. If such proposals were to be made after completion of this PEIS, DOE would conduct the appropriate level of review under the *National Environmental Policy Act* prior to making any decision on the proposals.

[2] As explained in Section S.4.6, the All-High Temperature Gas-Cooled Reactor Option, which is an open fuel cycle, would have the highest transportation impacts for truck transport due to the high number of spent fuel shipments associated with this alternative.

S.1.1 Purpose and Need for Agency Action

DOE's underlying purpose and need is to support expansion of domestic and international nuclear energy production, while reducing the risks of nuclear proliferation and reducing the impacts associated with the disposal of spent nuclear fuel (e.g., by reducing the volume, thermal output, and/or **radiotoxicity** of waste requiring geologic disposal). To meet its nonproliferation goals with regard to spent nuclear fuel recycling, DOE will assess, as reasonable alternatives, only those technologies that do not separate or use pure plutonium.

S.1.1.1 *Energy/Electricity*

> **Radiotoxicity**
>
> Radiotoxicity is a measure of the hazard posed by radioactive material. Radiotoxicity is an inherent property of the radioactive material, and represents the source of the potential hazard associated with exposure. It is a measure of the adverse health effects caused by a radionuclide due to its radioactivity. Because different radionuclides give different biological effects, the total radiotoxicity from a group of radionuclides is the sum of the radiotoxicity of each radionuclide. Since the radionuclides are decaying with time, the radiotoxicity also changes with time.

Electricity use in the United States is expected to continue to grow. In its most recent *Energy Outlook Report*, issued in June 2008, the Energy Information Administration (EIA), an independent organization within DOE, estimates that demand for electricity will increase by approximately 1.1 percent annually through 2030 (EIA 2008a). An early release of that report, issued in December 2007, estimated United States electricity growth at 1.3 percent annually through 2030 (EIA 2007a). This Draft PEIS utilizes the higher 1.3 percent growth rate; however, in the Final PEIS, DOE will consider whether any changes to the document are warranted to account for the 1.1 percent growth rate or other relevant information that becomes available. Based on an annual growth rate of 1.3 percent, electricity use could increase by approximately 40 percent by 2030, and if that annual rate were to continue, electricity use could double (relative to use in 2004) by approximately 2060.

With respect to the generation of electricity by nuclear power, which currently supplies approximately 19 percent of United States electricity needs, the Energy Information Administration estimated an annual growth of 0.6 percent in the June 2008 *Energy Outlook Report* and 0.7 percent in the December 2007 report (EIA 2008a, EIA 2007a). This Draft PEIS utilizes the higher 0.7 percent growth rate. When compared to the 1.3 percent annual growth in overall electricity use, nuclear energy's contribution to U.S. needs (its market share) would decline. This PEIS analyzes four different growth rates for electricity generation from nuclear power (0 or no growth, 0.7 percent, 1.3 percent and 2.5 percent for a high growth rate case). Unless indicated otherwise, the environmental impact analysis in this Summary is presented for a 1.3 percent growth scenario (which would equate to approximately 200 gigawatts of electricity (GWe)[3] from nuclear power in the 2060-2070 time frame).

[3] One GWe is equal to 1,000 megawatts of electricity.

Consistent with the President's 2006 **Advanced Energy Initiative**, DOE seeks to develop ways to support the expanded use of nuclear energy to meet growing electricity demand. DOE policies and actions resulting from decisions in response to this PEIS could affect subsequent decisions made by the U.S. commercial utility industry, which ultimately would determine how to meet the future increased demands for electricity.

Advanced Energy Initiative

Includes, in part, a combination of initiatives intended to accelerate research and development in three areas of power generation:

- National and international nuclear energy activities, such as the GNEP Program
- Coal-based clean power and carbon sequestration
- Renewable resources such as solar, wind and geothermal power.

S.1.1.2 *Spent Nuclear Fuel Disposal and Waste Reduction*

The *Nuclear Waste Policy Act* of 1982, as amended, provides for the disposal of spent nuclear fuel and high-level radioactive waste in the Nation's first proposed geologic repository to be located at Yucca Mountain, Nevada. Yucca Mountain is located in a remote desert on Federal land on and adjacent to the secure boundaries of the Nevada Test Site in Nye County, Nevada (DOE 2008f)[4]. Pursuant to the *Nuclear Waste Policy Act* of 1982 and by contract, the Federal government has responsibility for the disposal of commercial spent nuclear fuel currently being stored onsite at commercial reactor facilities.

Under the *Nuclear Waste Policy Act* of 1982, the statutory capacity limit for the Yucca Mountain repository is 70,000 **metric tons of heavy metal** (MTHM)[5] of spent nuclear fuel and high-level radioactive waste. DOE estimates that this statutory capacity limit will be reached by approximately 2010. Regardless of any DOE decision related to the GNEP PEIS, the Nation requires a permanent geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste. The GNEP Program has been proposed in addition to the Yucca Mountain

Metric Tons of Heavy Metal

Quantities of spent fuel are traditionally expressed in terms of metric tons of heavy metal (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of the refrigerated storage area in a typical household refrigerator.

4 The potential environmental impacts of the construction, operation, and closure of the Yucca Mountain repository are addressed in the *Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE/EIS-0250, February 2002) (DOE 2002i) and the *Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE/EIS-0250-S1) (DOE 2008f).

5 The *Nuclear Waste Policy Act* of 1982 (NWPA) limits the initial capacity of Yucca Mountain, the first proposed geologic repository, to 70,000 MTHM of spent nuclear fuel and high-level radioactive waste (DOE has allocated this capacity between 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE spent nuclear fuel and high-level radioactive waste) until such time as a second repository is in operation. In its cumulative impacts analysis, the Yucca Mountain Supplemental Environmental Impact Statement, issued in July 2008, evaluated the disposal of up to approximately 130,000 MTHM of spent nuclear fuel, equivalent to the amount projected from all existing commercial power reactors during all of their projected lifetimes. Disposal of more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste at the Yucca Mountain site prior to completion of a second repository would require a legislative change. DOE believes that if the statutory capacity limit is eliminated, then the Yucca Mountain geologic repository would have sufficient capacity to receive at least all of the spent nuclear fuel that has been or will be generated by the current fleet of nuclear power reactors.

Also, the current 70,000 MTHM statutory limit as defined in the NWPA pertains to the heavy metal content of the original fuel. As a result, from the standpoint of the Yucca Mountain geologic repository statutory capacity limit, it does not matter if spent nuclear fuel is emplaced as the original spent fuel rods, or spent nuclear fuel is reprocessed and only the resulting high-level waste is emplaced. While recycling spent nuclear fuel could significantly reduce the volume, radiotoxicity, and/or heat load in a future repository, recycling would have no impact on the initial Yucca Mountain repository capacity, because under current law its statutory capacity limit is based on initial MTHM (not volume, radiotoxicity, or heat load).

repository mandated by the *Nuclear Waste Policy Act* of 1982, and does not change the planning for the Yucca Mountain repository. Any decisions pursuant to the GNEP PEIS would not diminish in any way the need for the nuclear waste disposal program at a permanent geologic repository. Under all alternatives, spent nuclear fuel and/or high-level radioactive waste would continue to be produced and require disposal.

The GNEP PEIS assesses alternatives that would reduce the volume, thermal output, and/or radiotoxicity of spent fuel and wastes requiring geologic disposal for quantities in excess of the 70,000 MTHM that DOE has proposed for disposal in the repository at Yucca Mountain.

Reducing the volume, thermal output, and/or radiotoxicity could expand the number of acceptable sites for future geologic repositories, and could reduce both the cost and difficulty of siting and operating a geologic repository.

S.1.1.3 *Proliferation Risk Reduction*

It is a long-standing U.S. national security policy objective to reduce **proliferation risks** throughout the nuclear fuel cycle via systematic and comprehensive efforts to prevent the spread of nuclear weapon materials and sensitive technologies. Therefore, in order for the U.S. to support nuclear energy in an expanded role in the global energy market, the risk of proliferation needs to be addressed. Accordingly, DOE seeks to explore reliable nuclear fuel service programs to enable other nations to acquire nuclear energy economically while limiting the spread of sensitive fuel cycle technologies, particularly enrichment and reprocessing technologies. In addition, DOE seeks to advance programs to design and deploy nuclear reactors having less proliferation potential that are both cost effective and suited to conditions in developing nations.

> **Proliferation risks** relate to the potential use of the nuclear materials and/or technologies from the civil nuclear fuel cycle to make a nuclear weapon. Proliferation risks can result from the spread of sensitive nuclear materials and/or technologies.

Separate from the GNEP PEIS, the National Nuclear Security Administration, a separately organized agency within DOE, is preparing an assessment of the nonproliferation aspects of the programmatic alternatives evaluated in this GNEP PEIS. The draft assessment is expected to be publicly available in the same time frame as this Draft GNEP PEIS. The final assessment will be publicly available prior to the Record of Decision for this GNEP PEIS, and will be considered by DOE in decisions regarding the GNEP Program.

S.1.2 Public Participation

Regulations of the Council on Environmental Quality require "an early and open process for determining the scope of issues related to a proposed action" as part of NEPA compliance (40 CFR 1501.7). This activity is known as the public scoping process. The purpose of this scoping process is to inform the public about a proposed action and the alternatives being evaluated, and to solicit public comments on the range of reasonable alternatives and potential environmental impacts.

On March 22, 2006, DOE published an Advance Notice of Intent for the *Global Nuclear Energy Partnership Technology Demonstration Program Environmental Impact Statement* in the *Federal Register* (71 FR 14505). The Advance Notice of Intent explained the goals of the GNEP Program, three major elements of the then-proposed GNEP Technology Demonstration Program, and the purpose and need for action, and presented a list of potential environmental issues for analysis. In the notice, DOE also solicited comments on the proposed scope, alternatives, and environmental issues to be analyzed in the then-planned GNEP Technology Demonstration EIS. DOE received about 800 comment documents, including comments that DOE should prepare a PEIS of the entire GNEP Program, not just the GNEP Technology Demonstration Program.

On August 3, 2006, DOE announced that it would issue financial assistance grants to public or commercial entities interested in hosting GNEP facilities (DOE 2006n). DOE reviewed the resulting grant applications and on January 30, 2007, issued grants to 11 commercial and public consortia to conduct siting studies for hosting an advanced nuclear fuel recycling center and/or an advanced recycling reactor at the following sites: Atomic City, Idaho; Idaho National Laboratory, Idaho; Morris, Illinois; Paducah, Kentucky; Hobbs, New Mexico; Roswell, New Mexico; Portsmouth, Ohio; Barnwell, South Carolina; Savannah River Site, South Carolina; Oak Ridge Reservation, Tennessee; and Hanford, Washington.

On January 4, 2007, DOE published the Notice of Intent for the GNEP PEIS in the *Federal Register* (72 FR 331). That Notice of Intent explained the scope of the revised GNEP Program, identified the alternatives that were then proposed for evaluation, described the purpose and need for action, identified potential sites that could host GNEP Program facilities, and listed potential environmental issues for analysis. Subsequent to the Notice of Intent, DOE held public scoping meetings near the sites that were proposed and in Washington, DC.

DOE received approximately 14,000 comment letters/emails and oral comments related to the scope of the GNEP PEIS. The major scoping comments related to the purpose and need, the alternatives that were being considered, the various resource areas that should be addressed in the PEIS, and proliferation risk.

DOE considered all comments received in the preparation of this PEIS. Some of the key comments requested additional programmatic alternatives. In the Notice of Intent, DOE identified two programmatic alternatives for analysis—a No Action Alternative and the Proposed Action. Under the No Action Alternative, the U.S. would continue to rely upon a once-through fuel cycle in which commercial **light water reactors**, which are classified as **thermal reactors**, would use fuel one time and the resulting spent nuclear fuel would be stored for eventual disposal in a geologic

Types of Reactors

Light water reactor. A nuclear reactor using ordinary water to cool the reactor and to slow down (moderate) neutrons. Light water reactors belong to the class of nuclear reactors called **thermal reactors** (so called because they use slow, thermal neutrons to cause fission).

Advanced recycling reactor: A sodium-cooled **fast reactor** containing nuclear fuel comprising a blend of uranium and various transuranic elements (for example, plutonium) recovered from processed spent nuclear fuel. A **fast reactor** is a reactor in which the chain reaction is sustained by fast neutrons. These higher energy neutrons can fission all types of uranium and transuranic elements, rather than only the fissile isotopes split in thermal reactors. This allows the fast reactor to transmute (consume) the transuranics. Thus, fast reactors can extract energy from both uranium and transuranic elements.

repository. Under the Proposed Action, the U.S. would pursue a closed fuel cycle in a system that would process light water reactor spent nuclear fuel in one or more nuclear fuel recycling centers and would reuse some of the recovered materials in one or more **fast reactors** (also referred to as **advanced recycling reactors**). In response to scoping comments, the Department added four domestic programmatic alternatives that are evaluated in detail in this PEIS.

In response to public comments and as the programmatic analysis developed, DOE determined that to make project-specific or site-specific decisions regarding any of the three originally proposed facilities would be premature. The programmatic decisions to be made would influence the size and type of facilities required for implementing an alternative fuel cycle (the originally proposed nuclear fuel recycling center and advanced recycling reactor) as well as the facility needed to support research, development, and deployment (an Advanced Fuel Cycle Facility). As a result, no project-specific or site-specific proposals are being made at this time. Based on the proposed programmatic decisions, the DOE might make future proposals for particular actions. Any such proposals would be subject to appropriate NEPA review.

S.2 DOMESTIC PROGRAMMATIC ALTERNATIVES

This PEIS evaluates six domestic programmatic alternatives, which include both closed and open fuel cycles—a No Action Alternative (open cycle), three action alternatives with recycling of spent nuclear fuel (closed cycle), and two action alternatives without recycling of spent nuclear fuel. Figure S.2-1 provides a representation of the six domestic alternatives and the scope of the analyses in this PEIS. Each alternative is described in greater detail in Sections S.2.1–S.2.6.

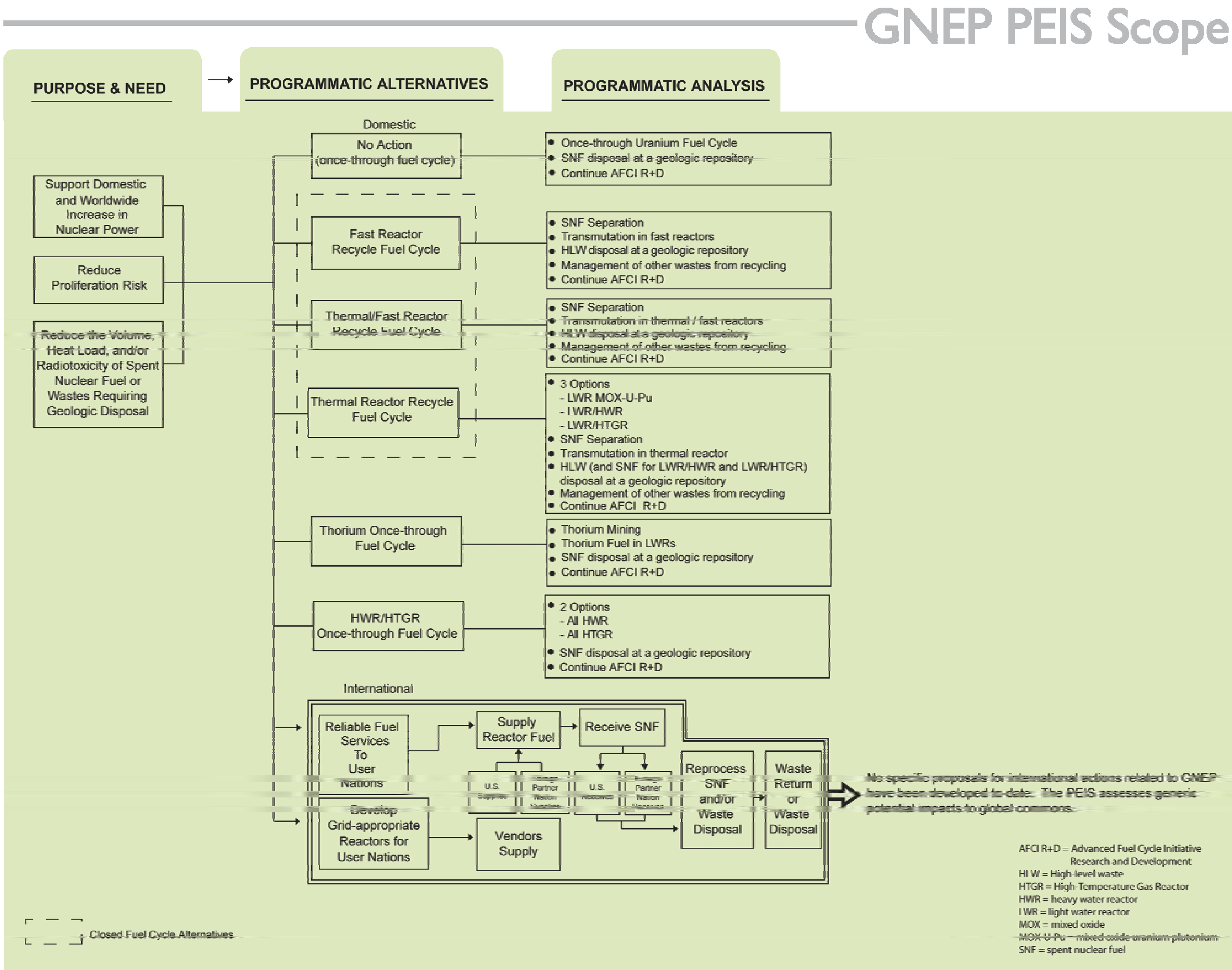


FIGURE S.2-1—*GNEP PEIS Scope and Alternatives*

S.2.1 No Action Alternative

The No Action Alternative, which is required in an EIS, provides a baseline from which to compare the environmental impacts of the action alternatives. Under the No Action Alternative, DOE would continue to support a once-through fuel cycle (Figure S.2-2) in which nuclear fuel would be used one time to generate electricity, and the resulting spent nuclear fuel would be stored for eventual disposal in a geologic repository. This alternative assumes that commercial reactors would be similar to those currently licensed by the Nuclear Regulatory Commission and those under consideration for licensing by the Nuclear Regulatory Commission (i.e., light water reactor and advanced light water reactor designs). In addition, this alternative assumes continued performance improvements in reactor operation (e.g., higher fuel **burnup** at discharge from the reactor).

> **Burnup** refers to the amount of energy generated per unit mass of fuel. Higher burnup fuels can reduce the total amount of spent nuclear fuel generated by providing more energy per fuel assembly. Improved performance as a result of higher fuel burnup would be pursued under all domestic programmatic alternatives.

Under the No Action Alternative, as well as under any of the action alternatives, DOE would continue activities associated with the Advanced Fuel Cycle Initiative and other related DOE programs, including programs that address safety, safeguards and security requirements for advanced fuel cycle technologies. The objective of the Advanced Fuel Cycle Initiative is to develop the technologies needed to: reduce the environmental consequences associated with spent nuclear fuel management, reduce the proliferation risk from the use of nuclear power, and extend uranium resources.

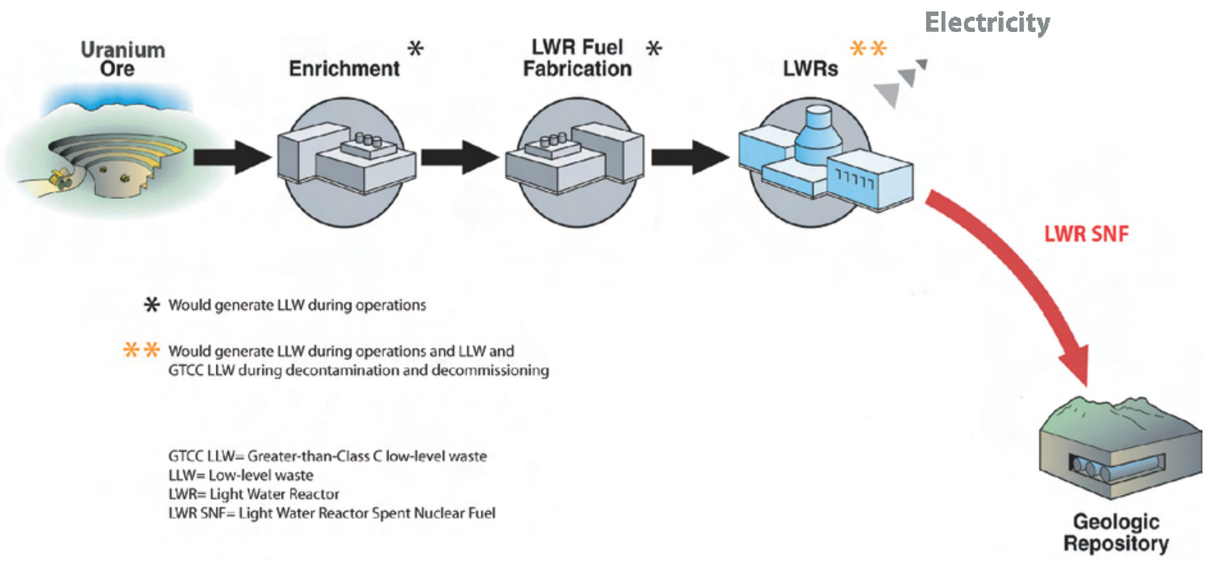


FIGURE S.2-2—*No Action Alternative Once-Through Uranium Fuel Cycle*

S.2.2 Fast Reactor Recycle Alternative

Under this alternative, DOE would support a domestic closed fuel cycle in a system that would process light water reactor spent fuel in a nuclear fuel recycling center and would recycle some of the recovered materials in advanced recycling reactors (i.e., fast reactors). The spent fuel from the fast reactors also would be processed to recover materials for repeated recycle in advanced recycling reactors.

Some uranium recovered during the recycling of light water reactor spent fuel would be used to fabricate new fuel for use in light water reactors and advanced recycling reactors.[6] **Transuranic elements** also would be recovered to be fabricated into new fuel, along with uranium, for use in advanced recycling reactors. Transuranic elements from spent nuclear fuel from advanced recycling reactors would also be recovered for further recycling. A balanced system in which the

> **Transuranic Elements**
>
> These are man-made elements that are heavier (i.e., have a higher atomic number) than uranium, and include, for example, neptunium, plutonium, americium, and curium.
>
> Transuranic elements are created in nuclear power plants when uranium absorbs or captures neutrons. Transuranic elements are generally long-lived and radiotoxic, and certain transuranic elements can be used in nuclear weapons.

[6] The uranium recovered could also be sold or stored for future use, or disposed of as low-level waste. This decision would likely be an economic issue and would be driven largely by the price of uranium.

amount of transuranics produced in light water reactors approximates the amount consumed in the advanced recycling reactors could be achieved with approximately 60 percent light water reactors and 40 percent fast reactors (Wigeland 2008a). Such a balanced system would avoid the accumulation of separated transuranics.

Under the Fast Reactor Recycle Alternative (Figure S.2-3), uranium and transuranic elements would be separated from other elements when processing light water reactor spent fuel and advanced recycling reactor spent fuel. A number of **advanced separations** technologies have been developed as part of the Advanced Fuel Cycle Initiative and through other international programs. One of these technologies could be considered for implementation, or an alternative technology that meets the separations requirements could be used. For nonproliferation reasons, DOE is not considering separations processes that produce a pure plutonium stream.

Advanced Separations

This PEIS considers the use of technologies that could separate spent nuclear fuel into usable and non-usable constituents. The objective of advanced separations is to allow options for management of particular elements in the spent fuel and reduce the wastes requiring geologic disposal.

Advanced separations technologies could provide the capability to selectively remove certain fission products (e.g., technetium, cesium, and strontium) and minor actinides (e.g., neptunium, americium and curium) from the high-level radioactive waste stream. The minor actinides could be recycled in reactors, while the fission products could be managed and disposed appropriate to their hazard.

Variations to existing separations technologies that have been developed and could be implemented in the near term would target the co-extraction of uranium and plutonium (and possibly neptunium) but would leave the other minor actinides and fission products in the high-level radioactive waste. Existing separations technology with variations could be deployed at commercial scale with confidence in its readiness. However, advanced separations technologies require research, development and demonstration prior to deploying at commercial scale.

Separating out minor actinides (and destroying them in a reactor) and select fission products would allow tailored management of the wastes streams and could significantly reduce the heat load and radiotoxicity of wastes requiring disposal in a geologic repository.

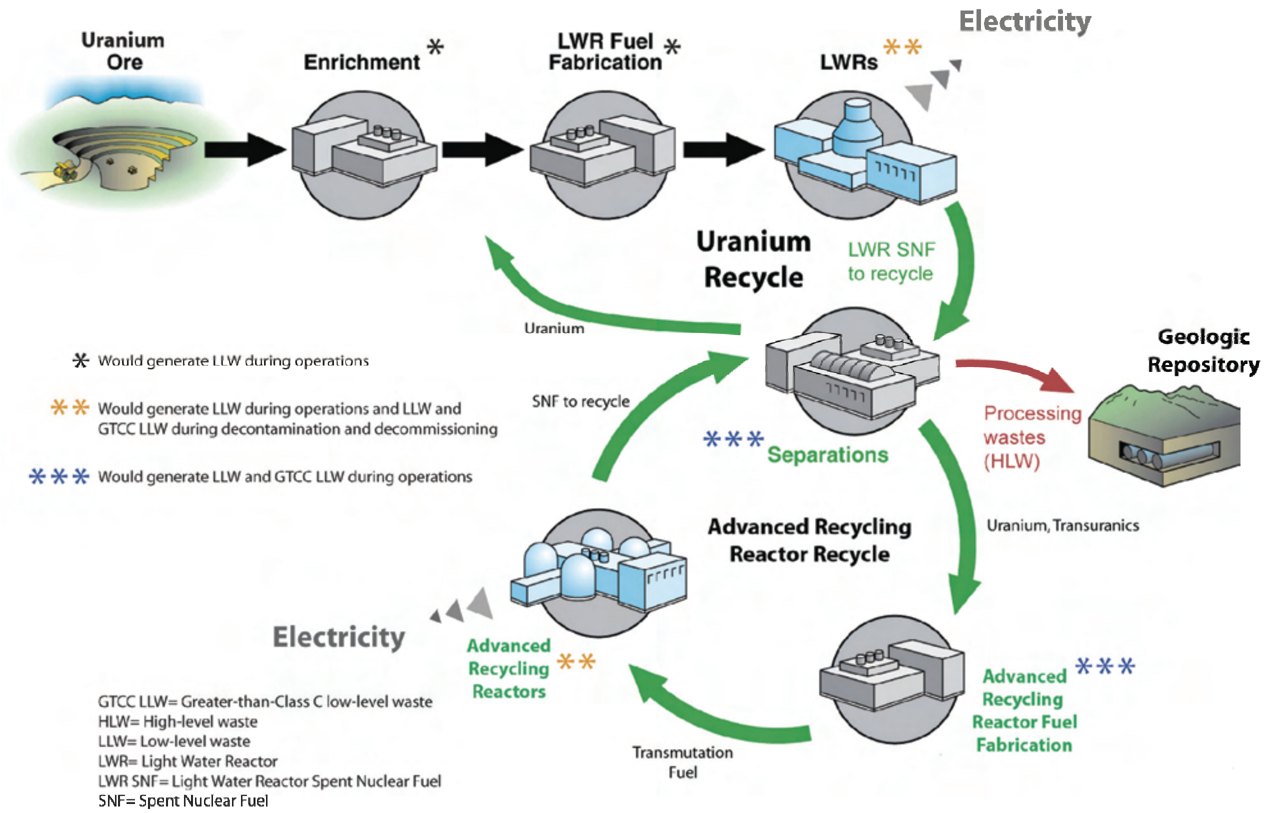


FIGURE S.2-3—*Fast Reactor Recycle Alternative*

The processing of spent nuclear fuel would result in high-level radioactive waste requiring eventual disposal in a geologic repository. The advanced separations technology could include the capability to separate cesium and strontium, which could be stored for about 300 years until they have become less radioactive, and then potentially disposed of as low-level radioactive waste. Alternatively, cesium and strontium could be disposed of as high-level radioactive waste in a geologic repository. In addition, implementation of this alternative would result in the generation of **Greater-than-Class-C low-level radioactive waste**, and low-level radioactive waste, both of which would require disposal. The Fast Reactor Recycle Alternative would require research and development (R&D) primarily in the following areas: fast reactor fuel fabrication and fuel performance; increasing fast reactor capacity to commercial scale; and scaling up fuel recycling (see Section S.3.1). Because transition to this fuel cycle would involve both new reactors and fuels, and the new fuels would require separations to provide feedstock, transition is expected to be more complex than most other fuel cycle alternatives (see Section S.3.2).

Greater-than-Class-C Low-Level Radioactive Waste

As defined by the Nuclear Regulatory Commission in 10 CFR 72.3, low-level radioactive waste that exceeds the concentration limits of radionuclides established for Class C waste in 10 CFR 61.55.

S.2.3 Thermal/Fast Reactor Recycle Alternative

Under this alternative, DOE would support a domestic closed fuel cycle in a system that would process light water reactor spent fuel in a nuclear fuel recycling center, and would recycle some of the recovered materials in both thermal reactors, such as light water reactors, and fast reactors. Such an approach would lower the number of fast reactors required to consume the transuranics generated in the light water reactors and allow recycling to start sooner by using existing reactors. A balanced system could be achieved with approximately 70 percent light water reactors and 30 percent fast reactors.

The process would separate light water reactor spent fuel into a combined uranium and plutonium product stream that would be used to fabricate a mixed oxide-uranium-plutonium fuel (referred to hereafter as MOX-U-Pu fuel) for use in light water reactors. Following use, the MOX-U-Pu spent fuel would be recycled and the recovered materials would be fabricated into new fuel for additional recycle in thermal or advanced recycling reactors. There are many variations that could be proposed for this approach, including which transuranic elements would be recovered, which would be recycled in thermal reactors, and which would be disposed of as waste.

Spent nuclear fuel would be processed to create new nuclear fuel, but the process would result in the same waste types (i.e., high-level radioactive waste, Greater-than-Class-C low-level radioactive waste, and low-level radioactive waste) as the Fast Reactor Recycle Alternative, but in different quantities and with different characteristics. The Thermal/Fast Reactor Recycle Alternative would require R&D in the same areas as the Fast Recycle Alternative. However, because the initial recycling would be performed in thermal reactors, near-term deployment of the Thermal/Fast Recycle Alternative is possible with variations to existing separations technologies, fuel, and reactor technologies. For example, for the initial recycle in thermal reactors, a MOX-U-Pu fuel has already been developed and is in use in Europe. From an implementation standpoint, because the Thermal/Fast Reactor Recycle Alternative would require limited development, licensing of a new fuel type, and the development of facilities to provide **feedstock** for the fuel, this alternative could start transition relatively quickly, compared to some of the other action alternatives (see Section S.3.2). This alternative differs from the Fast Reactor Recycle Alternative in that the Thermal/Fast Reactor Recycle Alternative could be implemented more quickly by use of existing thermal reactors and variations to existing separations technologies as the first step in this fuel cycle. The Thermal/Fast Reactor Recycle Alternative differs from the Thermal Reactor Recycle Alternative (Option 1) because in the longer term this alternative would transition to advanced separations technologies and fast reactors which would result in a greater reduction in the radiotoxicity and heat load of remaining spent nuclear fuel. Both the Thermal/Fast Reactor Recycle Alternative and the Fast Reactor Recycle Alternative have the potential for much greater reduction benefits in the radiotoxicity and heat load of remaining spent nuclear fuel than any other closed or open fuel cycles.

> **Feedstock** refers to the nuclear materials used to produce fuel for a reactor.

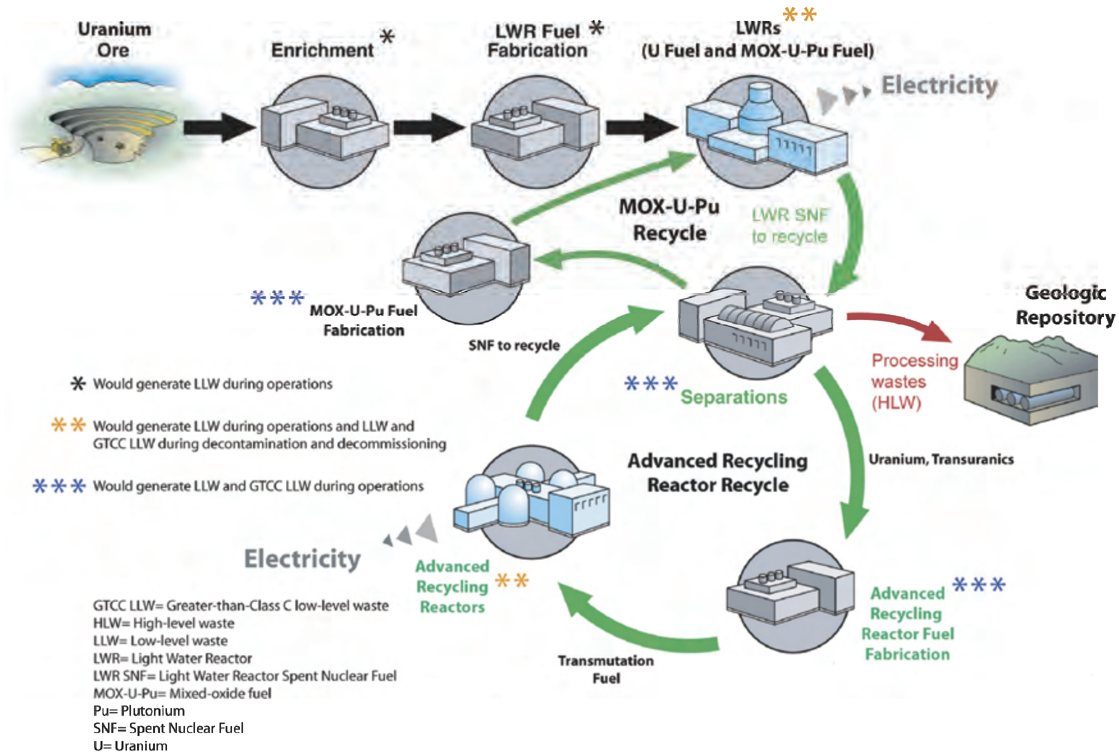


FIGURE S.2-4—*Thermal/Fast Reactor Recycle Alternative*

S.2.4 Thermal Reactor Recycle Alternative

Under this alternative, DOE would support a domestic fuel cycle that would process light water reactor spent nuclear fuel in a nuclear fuel recycling center, and would recycle some of the recovered materials to fabricate fuel for use in thermal reactors. The Thermal Reactor Recycle Alternative includes three options.

- Option 1: Recycle light water reactor spent fuel to produce a MOX-U-Pu fuel[7] for use in light water reactors
- Option 2: Recycle light water reactor spent fuel to produce fuel for use in heavy water reactors, and
- Option 3: Recycle light water reactor spent fuel to produce a transuranic fuel for use in high-temperature gas-cooled reactors.

S.2.4.1 *Option 1 – Thermal Reactor Recycle in Light Water Reactors*

Under Option 1, DOE would support a domestic closed fuel cycle in a system that would process light water reactor spent fuel at a nuclear fuel recycling center and recycle some of the recovered materials as new fuel for use in light water reactors. This option would involve the recycle of

[7] The use of a MOX-U-Pu fuel is analyzed as the baseline approach for this alternative. It would, however, be conceptually possible to use a mixed-oxide fuel with transuranics (referred to as MOX-TRU), particularly for the stabilization of the total transuranics, rather than disposing of the minor actinides in a repository. Chapter 4 discusses the major differences between the use of MOX-U-Pu fuel and MOX-TRU fuel.

uranium and plutonium for reuse in light water reactors using a fuel assembly concept that combines traditional uranium dioxide with mixed-oxide fuels.

This option would require facilities to recycle light water reactor spent fuel (using variations to existing separations technologies), and to fabricate MOX-U-Pu fuel. The MOX-U-Pu spent fuel would be recycled to recover the uranium and plutonium. Multiple recycle of plutonium in light water reactors would reduce the rate at which plutonium accumulates in the high-level radioactive waste that would require disposal in a geologic repository. During spent fuel recycling, this option would generate the same waste types as the Fast Reactor Recycle Alternative, but in different quantities and with different characteristics.

The Thermal Reactor Recycle Alternative (Option 1) would require R&D related to fuel development and fabrication, and large-scale recycling (see Section S.3.1). However, this alternative could start to transition sooner, and proceed through transition more quickly than many fuel cycle alternatives because it would only require development and licensing of a new fuel type and development of facilities to provide feedstock for the fuel (see Section S.3.2). Option 1 of the Thermal Reactor Recycle Alternative is shown in Figure S.2-5.

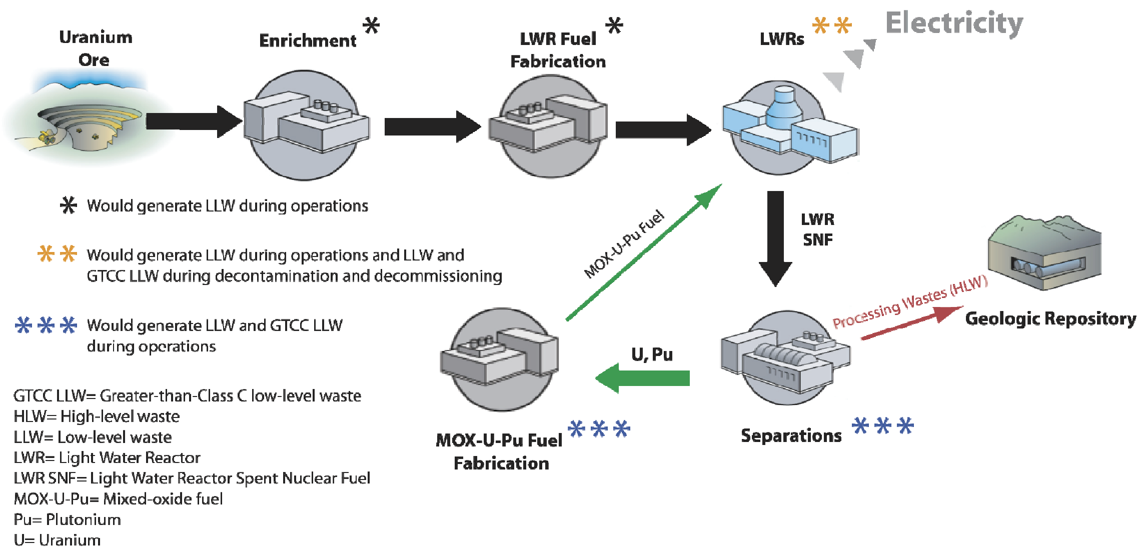


FIGURE S.2-5—*Thermal Reactor Recycle Alternative: Option 1 (Thermal Reactor Recycle in Light Water Reactors)*

S.2.4.2 *Option 2 – Thermal Reactor Recycle in Heavy Water Reactors*

Under Option 2, DOE would support a domestic closed fuel cycle in a system in which light water reactor spent nuclear fuel would be used as a source of fissile material to fuel **heavy water reactors**. This option would be possible because heavy water reactors require no or low initial fuel enrichment, which can be provided by light water reactor spent nuclear fuel. This is referred to in this PEIS

> **Heavy water reactors** are thermal reactors that use deuterium oxide (heavy water) as a moderator and coolant for the reactor core. Natural (non-enriched) uranium typically is used as fuel, although other fuels consisting of slightly enriched uranium, mixed oxides of plutonium and uranium, or mixed oxides of plutonium and thorium, can be used.

as DUPIC—the Direct Use of Spent Pressurized Water Reactor (a type of light water reactor) Fuel in CANDU.[8]

The basic concept of the DUPIC fuel cycle is to fabricate heavy water reactor nuclear fuel from light water reactor spent fuel, principally by use of dry thermal/mechanical processes. By utilizing light water reactor spent fuel as an energy source for heavy water reactors, approximately 50 percent more energy can be derived from the light water reactor fuel. A steady-state material balance for the DUPIC fuel cycle would require approximately 75 percent light water reactors and 25 percent heavy water reactors (Yang and Park 2006). Recycling the light water reactor spent fuel would generate the same waste types as the other recycle alternatives but in different quantities and with different characteristics. This option would also generate heavy water reactor spent fuel that would require disposal in a geologic repository.

The Thermal Reactor Recycle Alternative (Option 2) would require R&D related to fuel development and fabrication, and large-scale recycling. Because both light water reactors and heavy water reactors are widely used commercially, most transition issues would be related to spent fuel treatment to provide feedstock for the heavy water reactors. Additionally, the development and deployment of heavy water production facilities would be required. Option 2 of the Thermal Reactor Recycle Alternative is shown in Figure S.2-6.

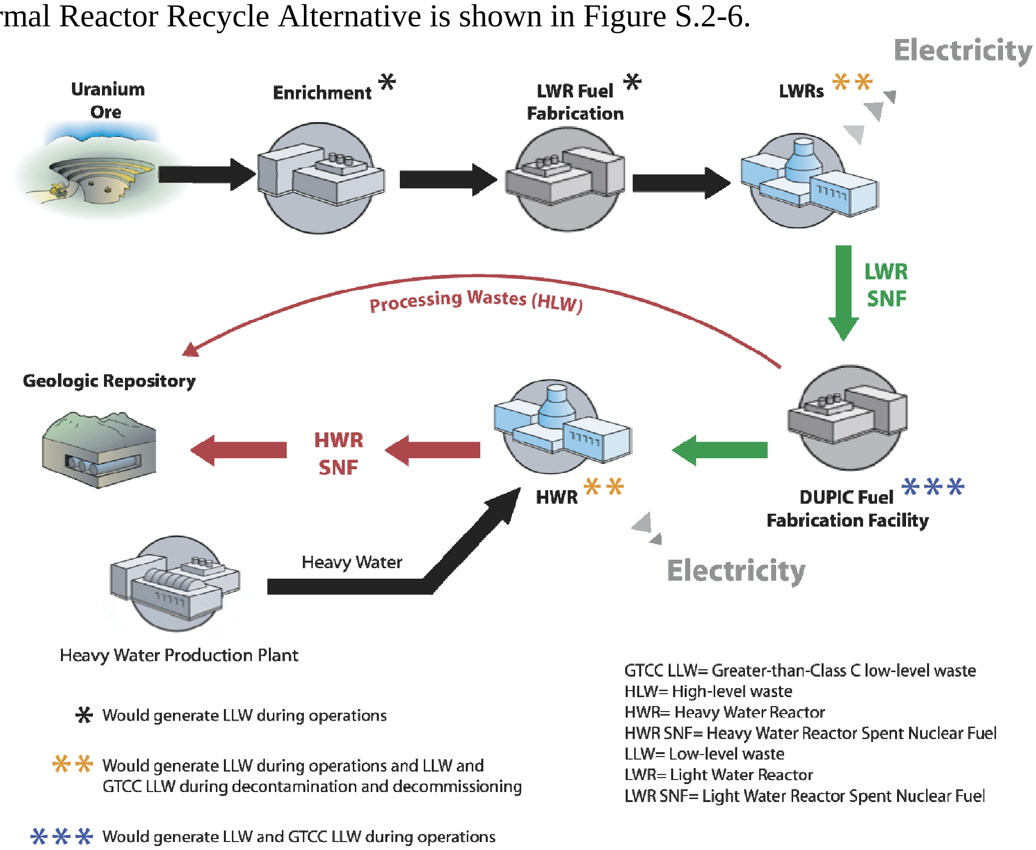


FIGURE S.2-6—*Thermal Reactor Recycle Alternative: Option 2 (Thermal Reactor Recycle in Heavy Water Reactors)*

[8] The acronym "CANDU," a registered trademark of Atomic Energy of Canada Limited, stands for "CANada Deuterium Uranium." This is a reference to its deuterium-oxide (heavy water) moderator and its use of natural uranium fuel.

S.2.4.3 *Option 3 – Thermal Reactor Recycle in High Temperature Gas-Cooled Reactors*

Under Option 3, DOE would support a domestic closed fuel cycle in a system that would recycle light water reactor spent nuclear fuel using advanced separations and use the recovered transuranic materials in **high temperature gas-cooled reactors** to achieve **deep-burn.** Recycling the light water reactor spent fuel would generate the same waste types as other recycle alternatives, but likely in different quantities and with different characteristics.[9] This option would also generate high temperature gas-cooled reactor spent fuel that would require disposal in a geologic repository. Based on a steady-state material balance for transuranic consumption, this alternative would require approximately 80 percent light water reactors and 20 percent high temperature gas-cooled reactors (Goldner and Versluis 2006).

> **High temperature gas-cooled reactors** are thermal reactors that use graphite as a moderator to slow down neutrons and gas (such as helium) to remove heat from the reactor core. Thorium, uranium or transuranic elements can be used as fuel.
>
> **Deep-burn** refers to the relatively high amount of transuranics that would be consumed in the high temperature gas reactor. For transuranic consumption of 60 percent, the burnup could be about 6-10 times greater than other reactor technologies.

The Thermal Reactor Recycle Alternative (Option 3—Thermal Reactor Recycle in High Temperature Gas-Cooled Reactors) is the least developed domestic programmatic alternative, with only limited data available. Many key data (such as the amount of light water reactor spent fuel that would be processed, the amount of transuranics to be recovered, and the deep-burn fuel composition) have not been determined. Much of the data that has been quantified has been from one of the principal high temperature gas-cooled reactor vendors. Data from the vendor indicate that a 70 percent reduction in transuranic waste and a two- to three-fold reduction in thermal heat load are possible (Goldner and Versluis 2006). The use of these data would indicate an improvement in meeting the purpose and need objectives compared to the No Action Alternative. While DOE has reviewed the information available, there is currently insufficient research available to verify that these data are correct. However, DOE believes that these data represent an initial estimate that can be used to reach some general conclusions that are not sensitive to the potential inaccuracies associated with such estimates. Consequently, any quantifications presented in this section for this option are only preliminary estimates, and do not have the same level of confidence as the data for other alternatives. DOE has recently sponsored additional research through the Generation IV program, which will result in information that will increase DOE's knowledge base regarding this concept, but this research will not be available for use in this PEIS.

This alternative would require significant R&D related to: fuel development and fabrication; large scale high temperature gas-cooled reactors that utilize a non-uranium fuel; and large-scale recycling of light water reactor spent fuel. This alternative would also require one or more reactor-grade graphite production plants, which currently do not exist in the United States. Transition to this alternative is considered complex (see Section S.3.2). Option 3 of the Thermal Reactor Recycle Alternative is shown in Figure S.2-7.

[9] Because the Thermal Reactor Recycle Alternative (Option 3) is the least developed domestic programmatic alternative, with only limited data available, it is not possible to quantify the specific differences in quantities and characteristics of wastes.

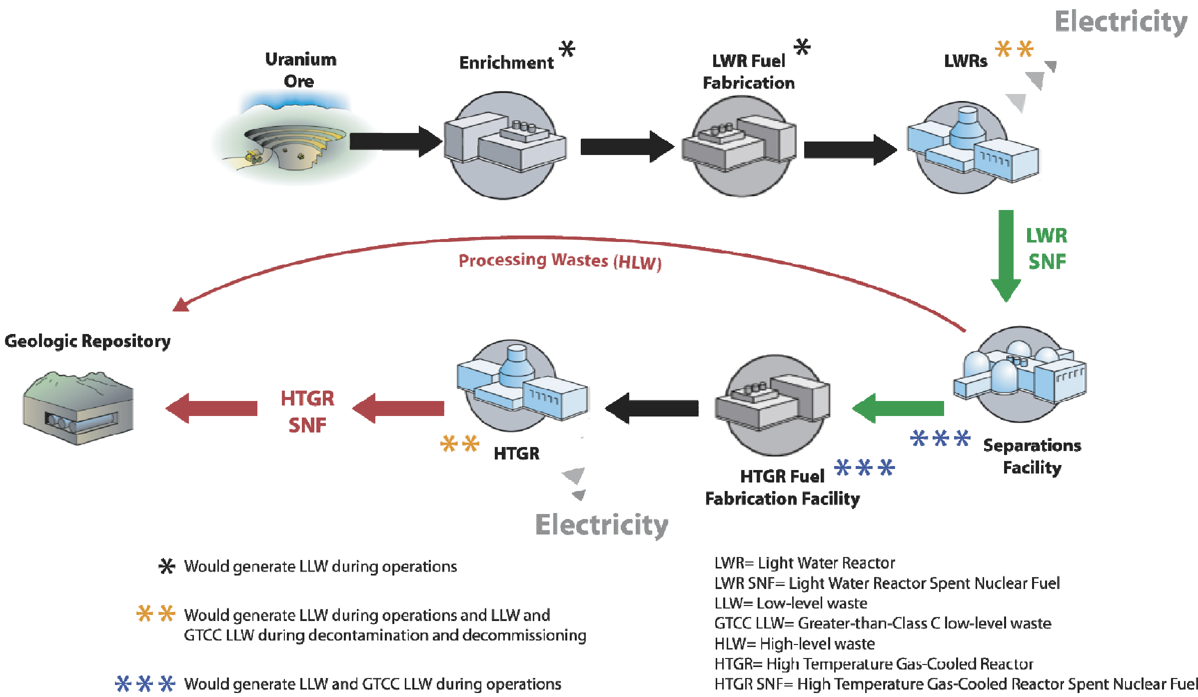


FIGURE S.2-7—*Thermal Reactor Recycle Alternative: Option 3 (Thermal Reactor Recycle in High Temperature Gas-Cooled Reactors)*

S.2.5 Thorium Alternative

Under this alternative, DOE would support a domestic open fuel cycle in a system that would use a thorium fuel in light water reactors. Thorium is a lighter element than either uranium or plutonium. As such, when thorium is used as a major component of reactor fuel, the production of transuranics (neptunium, plutonium, americium, and curium), which are the primary contributors to long-term waste radiotoxicity and heat load in geologic repositories, is reduced relative to conventional uranium-based fuels (IAEA 2002b).

The thorium once-through fuel cycle, while different in many aspects from the existing uranium once-through fuel cycle, can be characterized as a “new fuel design” rather than as a new reactor concept, because the thorium fuel cycle would be compatible with existing thermal reactors (e.g., light water reactors, heavy water reactors, high temperature gas-cooled reactors). The thorium fuel cycle would be feasible in most existing commercial nuclear power plants without major modifications to the engineered systems. Under this alternative, thorium-based spent nuclear fuel from the reactors would be stored for eventual disposal in a geologic repository.

The Thorium Alternative would require R&D related to fuel development and fabrication, and increasing reactor capacity to commercial scale. Transition could proceed relatively quickly because development and licensing of a new fuel type would be less complex than issues related to many of the other fuel cycle alternatives. The Thorium Alternative is shown in Figure S.2-8.

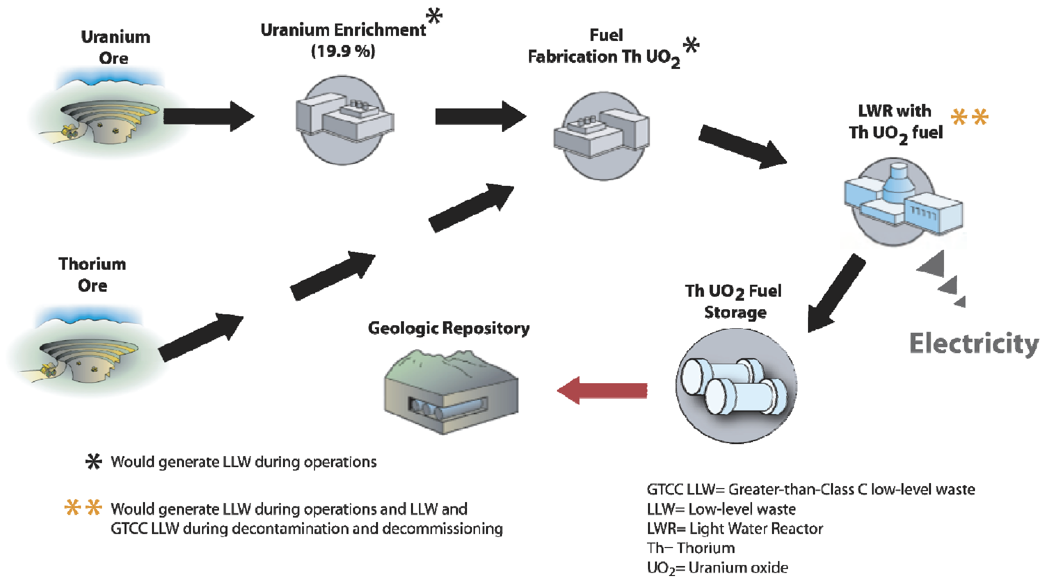


FIGURE S.2-8—*Thorium Fuel Cycle Alternative*

S.2.6 Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative

This alternative would involve a once-through fuel cycle that would use either heavy water reactors or high temperature gas-cooled reactors. Two options are assessed: Option 1—use heavy water reactors and Option 2—use high temperature gas-cooled reactors. In either option, the spent nuclear fuel would be stored until DOE could accept it for disposal in a geologic repository.

S.2.6.1 *Option 1 – Heavy Water Reactor*

Under this option (referred to hereafter as All-Heavy Water Reactor Option), DOE would support a domestic open fuel cycle in a system that would involve phasing out light water reactors in favor of heavy water reactors. With fewer neutrons absorbed by heavy water (600 times fewer) than normal light water, more are available to fission the uranium atoms in the fuel. This enables natural, rather than enriched, uranium to be used for fuel in a heavy water reactor. However, by using slightly enriched uranium, fuel cycle costs can be reduced compared to the natural uranium fuel cycle. This PEIS assesses the use of slightly enriched uranium in heavy water reactors (Figure S.2-9).

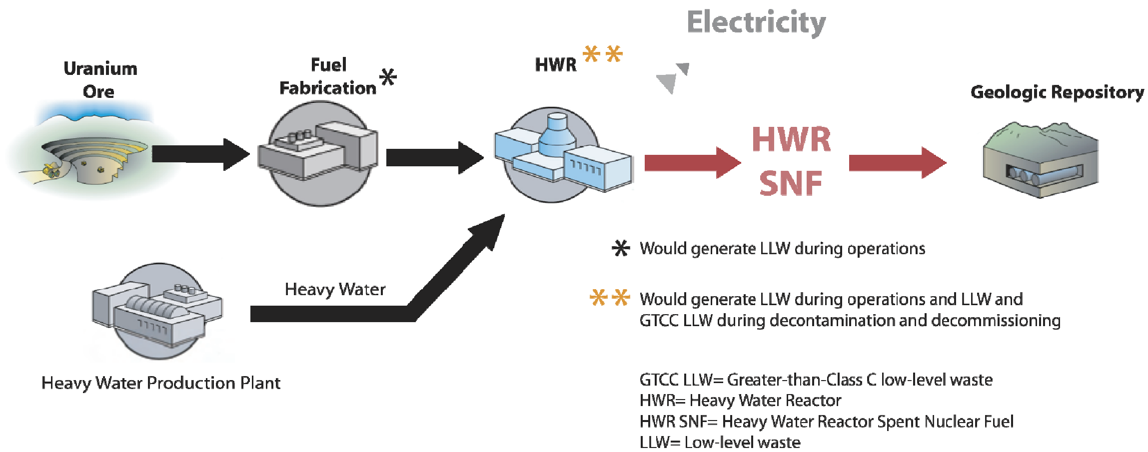


FIGURE S.2-9—*Heavy Water Reactor Open Fuel Cycle*

This alternative would require R&D related to fuel development and fabrication (see Section S.3.1). Because heavy water reactors are widely used commercially in other countries, transition issues would be less complex than for some other fuel cycle alternatives (see Section S.3.2). However, because heavy water reactors are not used commercially in the United States and commercial scale heavy water production facilities do not exist domestically, the development and deployment of heavy water production facilities would be required.

S.2.6.2 *Option 2 – High Temperature Gas-Cooled Reactor*

Under this option (referred to hereafter as the All-High Temperature Gas-Cooled Reactor Option), DOE would support a domestic open fuel cycle in a system that would involve phasing out light water reactors in favor of high temperature gas-cooled reactors. This option would use only uranium fuel and would not involve recycling. This option is shown in Figure S.2-10.

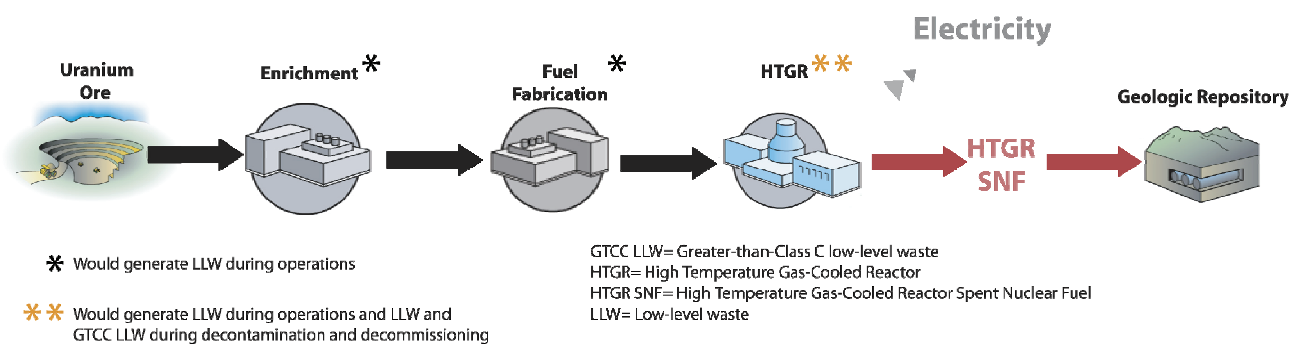


FIGURE S.2-10—*High Temperature Gas-Cooled Open Fuel Cycle*

This alternative would require R&D related to fuel development and fabrication, and increasing the capacity of high temperature gas-cooled reactors to commercial scale. This alternative would also require one or more reactor-grade graphite production plants, which currently do not exist in the United States. Transition to this alternative could be deployed once a new reactor type is available (see Section S.3.2).

S.2.7 Alternatives Considered but Eliminated from Detailed Study

In preparing this PEIS, DOE considered many alternatives for meeting the underlying purpose and need for agency action. DOE identified some of these alternatives through internal scoping, while the public identified others during the public scoping process. DOE reviewed each of these alternatives relative to their ability to meet the purpose and need to support the expansion of domestic and international nuclear energy production, while also reducing the impacts associated with disposal of spent nuclear fuel and the risks of nuclear proliferation. The alternatives considered but eliminated from detailed study are discussed below.

S.2.7.1 *Institute Interim Storage of Spent Nuclear Fuel*

DOE considered an alternative in which commercial spent fuel residing at each nuclear power plant site would be consolidated for centralized storage at one or more sites until ultimate disposal in a geologic repository. Proponents suggest that interim storage might support growth in nuclear electricity production by relieving the buildup of spent fuel at commercial reactor sites and reducing the amount of dry storage required at these sites. Interim storage would leave the spent fuel in a form that would make it difficult to steal or divert to other purposes, and centralized storage could also make the spent fuel easier to protect.[10]

DOE does not have the authority under law to accept commercial spent nuclear fuel for interim storage at this time. Furthermore, consolidating spent fuel would not reduce its volume and would have a limited effect on the use of space in a geologic repository from the standpoint of thermal output. In certain respects, interim storage would be analogous to the No Action Alternative but would defer a decision of what to do with spent nuclear fuel to the future. Even if current law were modified and interim storage was authorized and pursued, there would be additional costs and risks associated with handling and transport of the spent fuel from the utilities to the interim storage sites, and then again to a repository for disposal or to a recycling facility for processing. For these reasons, DOE has concluded that interim storage does not satisfy DOE's purpose and need to reduce impacts associated with the disposal of spent nuclear fuel and therefore, is not considered to be a reasonable alternative.

S.2.7.2 *Terminate the Advanced Fuel Cycle Initiative*

One of DOE's missions is to undertake R&D activities in support of civilian nuclear energy programs. The objective of the Advanced Fuel Cycle Initiative is to develop the technologies needed to: reduce the environmental consequences associated with spent nuclear fuel management, reduce the proliferation risk from the use of nuclear power, and extend uranium resources. During the scoping period, some commentors suggested that DOE terminate the ongoing Advanced Fuel Cycle Initiative as an alternative. DOE has determined that this alternative is unreasonable in that it would not advance the purpose and need for DOE's action, and would inhibit the nation's ability to conduct research necessary for its energy future.

[10] For example, centralized storage could use hardened storage technology that would provide better protection against terrorist attacks.

S.2.7.3 *Fuel Cycle and Related Reactor and Technology Alternatives*

As a result of scoping comments, DOE considered several alternatives associated with various fuel cycles and associated technologies, such as accelerators for transmutation, breeder reactors, different technologies to process spent fuel, fast reactor types other than sodium-cooled reactors, supercritical water-cooled reactors and molten salt reactors. DOE also considered the use of a thorium closed fuel cycle alternative, a high temperature gas-cooled reactor closed fuel cycle alternative and a MOX-U-Pu fuel open fuel cycle alternative.

> **PUREX**
>
> Plutonium and Uranium Recovery by Extraction (PUREX) is an aqueous separation process that has been used to extract uranium and plutonium independently from one another.

DOE eliminated some of these alternatives from detailed consideration because certain reactors (e.g., breeder reactors) or separations methods (e.g., **PUREX** process) would produce weapons-usable materials, which would be inconsistent with DOE's objective to decrease the inventory of pure plutonium. The long-term sustainability of nuclear energy may require breeder reactors at some time in the future if uranium resources become scarce or uneconomical to extract. The long-term sustainability of nuclear energy is, however, a mission of another DOE program: the Generation-IV Initiative (DOE 2006t).

Some technologies are not sufficiently viable or mature to enable meaningful analysis relative to other technologies analyzed in detail. DOE considers, for example, supercritical water-cooled or molten salt reactors, certain elements of spent fuel processing and recycling in a thorium closed fuel cycle and the use of accelerators to convert transuranic radionuclides to more stable and less radiotoxic elements, to be reactor or processing technologies that are not as advanced as those considered in detail in this PEIS. Other closed fuel cycle technologies are even more immature and tend to be impractical or unfeasible, such as processing spent fuel from high temperature gas-cooled reactors. The alternative to use MOX-U-Pu fuel in an open fuel cycle would produce spent fuel not amenable to substantially reducing the impacts of disposal; that is, it would not substantially reduce volume, thermal output or radiotoxicity.

S.2.7.4 *Increase Burnup of Light Water Reactor Fuels*

DOE considered an alternative in which light water reactor operations would significantly increase the burnup of light water reactor fuels, which would reduce the total amount of spent fuel generated, by providing more energy per fuel assembly. Any benefit from this volume reduction would be off-set by a larger quantity of fission products in the spent fuel, which would increase radiotoxicity and thermal output of the fuel. As a result, increased burnup of light water reactor fuels was not analyzed as a discrete alternative.

S.2.7.5 *Recycle Spent Nuclear Fuel Planned for the Yucca Mountain Repository*

During the scoping period, some commentors suggested that DOE should recycle the spent nuclear fuel that is now planned for disposal at the Yucca Mountain repository. Some commentors stated that recycling this spent nuclear fuel could eliminate the need for the Yucca Mountain repository. Under all nuclear fuel cycles, however, the United States will need a permanent geologic repository to dispose of spent nuclear fuel and/or high-level radioactive waste from the operation of commercial nuclear power plants and defense-related activities. All programmatic alternatives analyzed in this PEIS, including the No Action Alternative, would require at least one geologic repository; the GNEP PEIS would have no effect on the ongoing planning for that initial repository. GNEP PEIS alternatives are at a stage of initial proposal, and DOE has not made any decisions to proceed with any specific alternative. Given the many uncertainties associated with the timing and the scope of the implementation of any action alternative that might be selected here, the present pressing need for disposal capacity that the Yucca Mountain repository is intended to address, and current statutory mandates, it is reasonable and necessary to go forward with the Yucca Mountain repository as planned. Consequently, the GNEP PEIS does not address the recycle of spent nuclear fuel currently planned for disposal at the Yucca Mountain geologic repository (i.e., up to the statutory capacity limit).

S.2.7.6 *Non-nuclear Electricity Production*

Some commentors suggested that the United States should meet future electricity demands through conservation and increased use of renewable energy sources, rather than through increased use of nuclear energy. While DOE agrees that conservation and increased use of renewable energy resources are needed, DOE seeks to support the expansion of nuclear energy as one element of a diverse portfolio of power-generation systems. Thus, DOE recognizes that the alternatives in this PEIS, which relate exclusively to nuclear fuel cycles, are not "either/or" alternatives with respect to the various options for meeting future electricity demands. Programs other than GNEP address renewable energy and energy conservation.

S.3 IMPLEMENTATION OF DOMESTIC ALTERNATIVES

The Department recognizes that deployment of any of the domestic programmatic alternatives would occur largely as a result of actions of private industry, which would be driven primarily by market forces. Other factors, such as future national policies and regulatory issues, might also influence the nature of, and degree to which any of the alternatives would be deployed. While it is not possible to predict with confidence how any of the alternatives would be implemented on a national scale, DOE assumes that these factors would not ultimately be barriers to the widespread implementation of any alternative. Nevertheless, DOE in this PEIS considers certain factors that are likely to have a bearing on the extent to which the alternatives could be implemented by private industry: the need for R&D, the costs and timing of transition to and implementation of the alternatives, and the design and operation of a future geologic repository.

S.3.1 Research and Development Needs

Many of the alternatives require additional R&D before wide-scale deployment could be accomplished. Below, R&D needs are grouped by technical area and compared among the alternatives.

- <u>Fuel Development and Fabrication</u>: The need for R&D of fuel fabrication technologies is considered from two perspectives: first, whether a fabrication technology exists, and second, whether the existing technology has been developed sufficiently to allow an alternative to be implemented. Most of the alternatives have candidate processes for fabrication of fuel; however, all but the No Action Alternative and the All-Heavy Water Reactor Option would require additional R&D to apply these technologies. The time frame to complete the necessary R&D would be similar among the alternatives and is estimated to require about 5 to 10 years.

– Fuel Performance: R&D would be required to develop and demonstrate fuel performance in the reactor and in storage after discharge from the reactor (whether destined for processing or not) for each of the alternatives, except for the No Action Alternative and the All-Heavy Water Reactor Option, which utilize proven fuel technologies. For most alternatives, relevant fuel performance experience is available, although for some of the reactor types this experience may be limited to experimental or testing conditions only. Even for reactor types for which there may be prior commercial experience, it is likely that testing and verification of fuel performance would be required as one of the licensing conditions, regardless of the alternative, prior to widespread use (with the exceptions of light water reactors and heavy water reactors). In contrast, it is also likely that each reactor type, whether commercially available or not, could begin operations using nuclear fuel that is within the existing experience base, and then move toward the required fuel composition as new experience is gained.

  Some of the alternatives would use reactor types that are not available in the United States, although either they have existed in the United States in the past as experimental or first-of-a-kind commercial plants, or they exist outside of the United States. For example, heavy water reactors are used extensively in Canada, which would likely facilitate licensing in the United States. For alternatives involving fast reactors and high temperature gas-cooled reactors, no facility exists in the United States where fuel performance experience sufficient for licensing can be acquired. Even for those alternatives where light water reactors would be used, it is likely that the licenses of existing light water reactors would need to be amended to allow fuel performance tests, and this may not be possible. The time frame for achieving the required fuel performance information would depend on the availability of the appropriate irradiation facilities, but such development could be done as part of the ongoing operation of the facility.

– Reactor Technology: Each of the reactor technologies associated with the domestic programmatic alternatives have different operating experience, which could affect the amount of R&D needed to implement that technology. For example, light water reactors and heavy water reactors are used throughout the world and would not necessarily require any new R&D. Other reactor technologies (thorium-fueled reactors,[11] fast reactors and high temperature gas-cooled reactors) have been operated on much smaller scales than light water reactors and heavy water reactors: therefore, these reactor technologies would benefit the most from R&D. The high temperature gas-cooled reactor, in particular, would require the most R&D, as the operating experience with this reactor technology at industry-scale (greater than 250 megawatts) has been limited.

[11] Although the Thorium Alternative is characterized as a "new fuel design" rather than as a new reactor concept in this PEIS, the insertion of thorium fuel into a light water reactor would not be as simple as, for example, the substitution of MOX-U-Pu fuel assemblies for uranium fuel assemblies in a light water reactor. Consequently, the need for R&D related to the use of thorium fuel is included under the "Reactor Technology" category in this section.

- Spent Fuel Processing: Only the closed fuel cycle alternatives require processing of spent nuclear fuel. For these alternatives, processing technologies have been developed and tested that would meet separations requirements. Some of the new technologies are evolutions of technologies that have been operated at commercial scale, and for those, implementation would expedite the required scale-up. There are many subsidiary issues associated with each new technology that would require R&D, especially with final treatment and consolidation of the wastes and with ensuring that the new technologies are capable of limiting releases of radioactive materials from the processing plant to allowable limits. The time frame for completing the required R&D is estimated to be 5 to 10 years for each of the closed fuel cycle alternatives.

- Spent Fuel and High-Level Radioactive Waste Disposal: All fuel cycle alternatives would require disposal of spent nuclear fuel and/or high-level radioactive waste in a geologic repository. DOE has already conducted significant R&D related to such disposal at the proposed Yucca Mountain repository and has submitted a license application for construction authorization with the Nuclear Regulatory Commission. The need for R&D related to geologic disposal in any future geologic repository would depend on the characteristics of the future geologic repository as determined by a site-specific assessment of repository performance (i.e., how well the repository would contain radionuclides). Such a performance assessment would consider: the form of the materials to be disposed of, barriers to release (e.g., waste packages and engineered repository systems), characteristics of the geologic environment (e.g., presence of water, chemistry of water, temperature, rock stability) and exposure pathways. DOE estimates that it would take 5 to 10 years or longer to complete such a R&D review. Testing of the waste forms under accelerated repository-relevant conditions could be accomplished more quickly. However, experimenting with changes to the formulation of proposed waste forms to enhance performance, if deemed necessary for a particular repository concept, could add years to such an effort.

S.3.2 Transition and Implementation

All alternatives, except the No Action Alternative, would involve an evolution from the current nuclear power generating system to one involving a new system. The environmental consequences during transitioning to the new system would be a mix of the No Action Alternative effects and the effects of the new system. The alternatives have been grouped where aspects of the transition analysis are similar:

Group 1: Alternatives that require new fuels with current reactor types. This includes the Thorium Alternative and the Thermal Reactor Recycle Alternative (Option 1).

Group 2: Alternatives that require transition from the current light water reactors to a single new reactor type. This includes the All-Heavy Water Reactor Option and the All-High Temperature Gas-Cooled Reactor Option.

Group 3: Alternatives that require transition to a system involving more than one reactor type in a balanced system. This includes the Fast Reactor Recycle Alternative, the Thermal/Fast Reactor

Recycle Alternative, the Thermal Reactor Recycle Alternative (Option 2) and the Thermal Reactor Recycle Alternative (Option 3).

The first group of alternatives (the Thermal Reactor Recycle Alternative—Option 1 and the Thorium Alternative) could start the transition sooner than some of the other fuel cycle alternatives and complete the transition more quickly, because Group 1 would primarily require only development and licensing of new fuel types and development of facilities to provide materials for these fuels. For the Thermal Reactor Recycle Alternative (Option 1), MOX-U-Pu fuel has been fabricated and is in use in Europe. Thorium fuel has been used in the past, but may require some reactor R&D and new data to satisfy licensing requirements.

The Thermal Reactor Recycle Alternative (Option 1) would require separations of light water reactor spent fuel to provide material (feedstock) to develop and fabricate the new fuel. Existing technologies, with some modification, could then support the recycle of MOX-U-Pu spent fuel as it becomes available.

Thorium fuel would obtain its feedstock of uranium and thorium from mining and stockpiles; adequate uranium mining exists and reliable reserves of thorium are available both in the United States and around the world. The level of enrichment of the uranium for the thorium fuel would be much higher, and would require new enrichment facilities. Both Group 1 alternatives would require construction or modification of fuel fabrication facilities.

Because the necessary technologies and facilities are understood, transition from the current system could begin within approximately 10 to 15 years. During such a transition, the new fuel could be used as a replacement during refueling, and specific reactors could switch over to the new system during a period of 5 to 6 years. A balanced system under the Thermal Reactor Recycle Alternative (Option 1) would also require recycle of the MOX-U-Pu spent fuel, which could begin roughly 5 years after it is discharged from the reactors. Thus, transition from the current light water reactor uranium oxide system to a Group 1 alternatives system could be completed in about 20 to 25 years. Transition could take longer if the principal technology uncertainties of the Thermal Reactor Recycle Alternative (Option 1) (i.e., separations capacity) and the Thorium Alternative (i.e., fresh fuel infrastructure, including facilities to enrich uranium to 19.9 percent [Todosow 2007b]) require additional time to resolve.

The second group of alternatives (the All-Heavy Water Reactor Option and the All-High Temperature Gas-Cooled Reactor Option) could be deployed once these reactor types were developed and licensed by the Nuclear Regulatory Commission. Heavy water reactors are available commercially internationally and would only require U.S. licensing, while high temperature gas-cooled reactors would require development of both the reactor and the fuel, which could take 10 to 15 years or longer. Feedstock would not be a constraint, because both options would depend on the existing uranium fuel infrastructure. Complete transition would require early construction of production facilities, including heavy water production plants for heavy water reactors and reactor-grade graphite production plants for high temperature gas-cooled reactors. The completion of transition would occur once all current (legacy) reactors were retired. Based on licensing and license extension considerations, DOE expects that reactors in the existing light water reactor fleet would be operated for 60 years, with retirements beginning in

2029 and completing in 2053. Construction of new light water reactors now under consideration could extend the transition period.

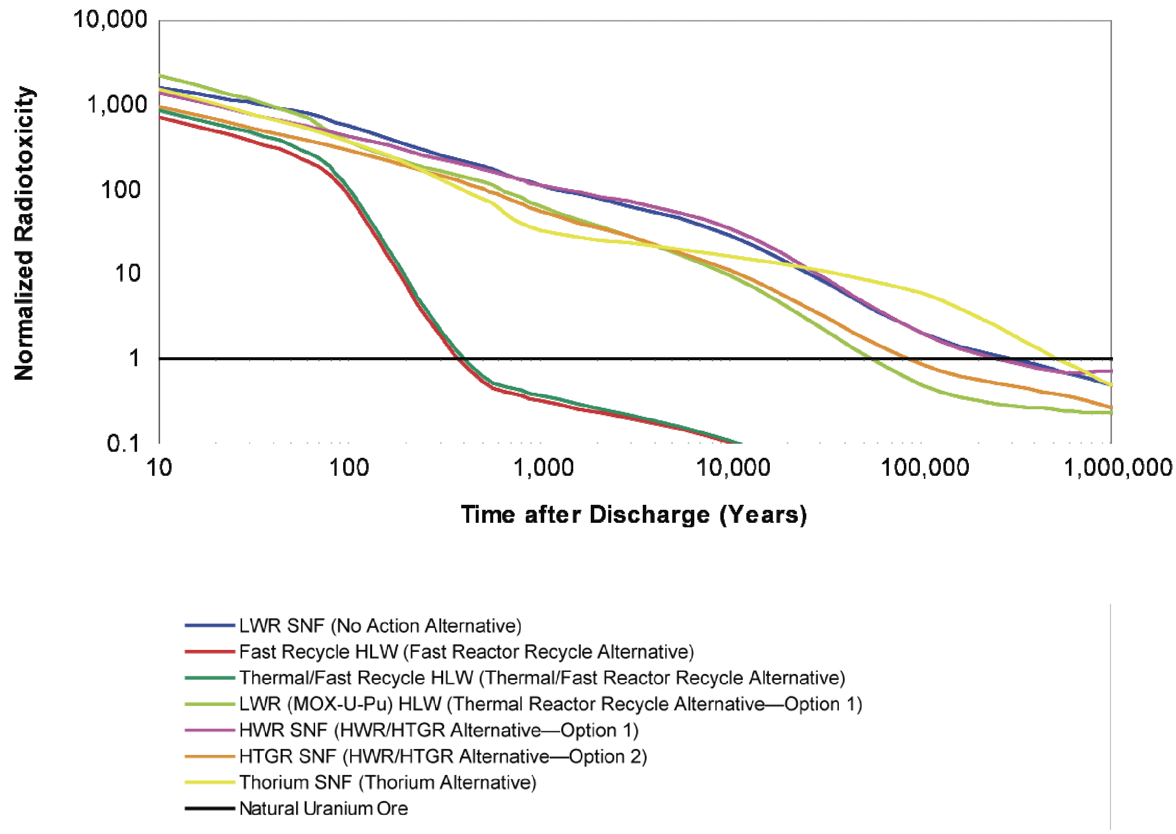
Transition for the final group of alternatives (the Fast Reactor Recycle Alternative, the Thermal/Fast Reactor Recycle Alternative, the Thermal Reactor Recycle Alternative (Option 2), and the Thermal Reactor Recycle Alternative (Option 3)) would be more complex relative to the Group 1 and Group 2 alternatives. The start of transition would involve new reactors and new nuclear fuels, and the new fuels would require separations to provide feedstock. Transition could begin in 15–20 years, but the rate of transition would be slower than the other groups of alternatives. This would be due to the feedstock required for startup of the new reactors, a full core of fuel would be needed to start each new reactor, while for the previous groups only a partial core would need to be replaced at a time. The feedstock would initially come from light water reactor spent fuel separations, and therefore would be tied to the separations capacity. While this would not affect deployment of heavy water reactors associated with the Thermal Reactor Recycle Alternative (Option 2), it could constrain the rate of fast reactor deployment, each of which would require a significant quantity of transuranics. The amount of transuranics needed to start up a new fast reactor would also depend on whether the fast reactor spent nuclear fuel would be recycled on-site or at a central facility. Centralized recycling would require longer storage of the fast reactor spent nuclear fuel so it could cool prior to transport. This could result in a greater delay before any of the residual transuranics from the fast reactor spent fuel could become available, so more transuranics would be required from separated uranium oxide before any would be available from the fast reactor spent fuel. The result would be that transition would not be completed for several decades.

S.3.3 Design and Operation of a Future Geologic Repository

The programmatic alternatives could impact, beneficially, the design and/or operation of a future geologic repository by reducing the radiotoxicity, heat load, or the volume of spent nuclear fuel and high-level radioactive waste. These reductions have the potential to decrease the uncertainty in predicting long-term performance of such a repository, or increase the public acceptability of geologic disposal, so that adequate disposal capacity can be found for future commercial nuclear waste inventories.

<u>Potential Reduction in Radiotoxicity</u>: Radiotoxicity, which is a measure of the hazard posed by radioactive material, is a function of time in part because the radiotoxicity from any isotope will be reduced to negligible levels as radioactive materials decay over time, although the decay process can require millions of years for some isotopes. One measure of the potential hazard of spent fuel and high-level radioactive waste is to compare the time required for the radiotoxicity of these radioactive materials to be reduced to that of the natural uranium ore used as the source material for the nuclear fuel. Although such a comparison is informative, it should be noted that radiotoxicity is not a regulatory standard relevant to the disposal of spent fuel and high-level radioactive waste.

Figure S.3-1 shows the radiotoxicity of the various types of spent nuclear fuel and/or high-level radioactive waste relative to uranium ore as a function of time. Table S.3-1 includes the time required for the spent nuclear fuel and high-level radioactive waste to decay to the radiotoxicity of natural uranium ore. As shown, spent fuel from light water reactors remains more radiotoxic than uranium ore for about 240,000 years. Alternatives that do not recycle spent fuel and transmute the long-lived actinides (with either fast reactors or thermal reactors) would generate waste that would remain more radiotoxic than the original natural uranium ore for approximately 85,000 to 525,000 years (Wigeland 2008a).



Source: Modified from Wigeland 2008a

FIGURE S.3-1—*Radiotoxicity of Spent Nuclear Fuel and/or High-Level Radioactive Waste Over Time*

Implementation of the Thermal Reactor Recycle Alternative (Option 1) could reduce the time period for which the radiotoxicity of the radioactive materials exceeds that of uranium ore to approximately 55,000 years. Implementation of the Fast Reactor Recycle Alternative or the Thermal/Fast Reactor Recycle Alternative could further reduce the longer-lived transuranic isotopes remaining in the radioactive wastes. Removal of uranium and transuranic elements via recycling could reduce the time period for which the radiotoxicity of the waste exceeds that of uranium ore from between approximately 85,000 and 525,000 years to perhaps less than 1,000 years, depending on the amount of uranium and transuranic loss from all processes that eventually becomes part of the wastes destined for disposal.

Potential Reduction in Thermal Load: Thermal load is a potentially relevant measure for geologic disposal because a repository would have thermal limits on both the engineered structures and the repository environment. For purposes of analysis in the PEIS, the thermal load reduction factor on a repository is 1.0 for the No Action Alternative, and the relative thermal load reduction of the action alternatives is compared to this value. For example, the high-level radioactive waste associated with the Fast Reactor Recycle Alternative and the Thermal/Fast Reactor Recycle Alternative would reduce the thermal loading on a repository by a factor of approximately 235 for the same total electricity generation (i.e., these alternatives could generate 235 times as much electricity as the No Action Alternative before producing the same thermal loading on a repository) (Table S.3-1). With respect to the other action alternatives, DOE estimates that thermal load reduction factors would range between 0.9 and 2.0. While most alternatives show an improvement compared to the No Action Alternative, recycling light water reactor and fast reactor spent fuel would achieve the most significant improvements in repository thermal loading.

Potential Reduction in Volume: The volume of radioactive materials requiring geologic disposal can be determined by the mass of material to be disposed multiplied by the concentration of waste in the final waste form, then adjusted to reflect the volume of surrounding waste packaging. For example, one potential waste form is borosilicate glass, for which there is a maximum radionuclide concentration that would dissolve into the glass, which in turn would determine the maximum waste loading. The glass would then be put into a waste package, the design of which is yet to be determined for a future geologic repository.

As shown in Table S.3-1, the annual volume of spent nuclear fuel generated by the open fuel cycle alternatives (e.g., No Action Alternative, Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative) is much greater than that of the closed fuel cycle alternatives (e.g., Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative) in which the spent fuel is recycled. In contrast, the closed fuel cycle alternatives would generate high-level radioactive waste requiring geologic disposal, and Greater-than-Class-C low-level radioactive waste, neither of which is generated by operations related to the open fuel cycle alternatives. DOE recognizes that the volume of high-level radioactive waste could be reduced by employing advanced methods to separate long-lived fission products (such as technetium and iodine) from potentially useful products (such as uranium and transuranic elements) and potentially from cesium and strontium.

TABLE S.3-1—*Comparative Summary of Programmatic Alternatives (Steady-State 200 Gigawatts of Electricity)*

Case Description	No Action (Once-Through Fuel Cycle)	Fast Reactor Recycle Alternative	Thermal/ Fast Reactor Recycle Alternative	Thermal Reactor Recycle Alternative			Thorium Alternative (Once- Through Fuel Cycle)	HWR or HTGR Alternative (Once-Through Fuel Cycle)	
				Option 1—Thermal Recycle in LWRs	Option 2—Thermal Recycle in HWRs	Option 3—Thermal Recycle in HTGRs		All HWR	All HTGR
Reactor Power Production[a] (200 GWe)									
LWR–UOX or HWR–UOX or HTGR–UOX (GWe)	200 LWR	120 LWR	126 LWR	0	146 LWR	164 LWR	0	200 HWR	200 HTGR
LWR–MOX-U-Pu, LWR-HWR, or LWR-HTGR (GWe)	0	0	14 LWR	200 LWR	54 HWR	36 HTGR	0	0	0
Fast Advanced Recycling Reactor (ARR) (GWe)	0	80 ARR	60 ARR	0	0	0	0	0	0
LWR–ThOX/UOX (GWe)	0	0	0	0	0	0	200 LWR	0	0
Fuel Burnup at Discharge (GWd/MTHM)	51	51 (LWR) 107 (ARR)	51 (LWR) 50 (LWR – MOX/Pu) 105 (ARR)	45	35 (UOX) 15 (HWR)	ND	149 (UOX) 75 (ThOX)	21	100
Other Facilities Required									
Enrichment Facility	yes	yes	yes	yes	yes	yes	yes	yes	yes
Fuel Fabrication Facility	yes	yes	yes	yes	yes	yes	yes	yes	yes
Heavy Water Production Facility	no	no	no	no	yes	no	no	yes	no
Nuclear Fuel Recycling Center	no	yes	yes	yes	yes	yes	no	no	no
Uranium (Natural and Low-Enriched Uranium) or Thorium Resource Requirement (Annual)									
Natural U Feed (MT/yr)	39,200	24,400	25,400	33,000	25,600	ND	39,200	42,800	45,600
LEU (MT/yr)	4,340	2,700	2,800	3,320	3,600	ND	820 (UOX) 160 (ThOX)	10,600	1,540
LEU Enrichment (%)	4.4	4.4	4.4	4.6	3.5	ND	19.9 (UOX) 12.2 (ThOX)	2.1	14.0
Natural Thorium (MT/yr)	0	0	0	0	0	0	1,070	0	0
SNF/ TRU Radionuclides in HLW and/or SNF / Cs/Sr storage / Recovered U storage (Annual)									
Amount of TRU to waste (MT/yr)	56	0.20	0.22	16.6	30	ND	15.6	76	32
Mass of SNF to repository (MTHM/yr)[b]	4,340	0	0	0	3,600	ND	2,050	10,600	1,540
Mass of Cs/Sr (MT/yr)	0	24	24	24	0	ND	0	0	0
Volume of Cs/Sr (m^3/yr)[c]	0	LB: 17-120 UB: 300	LB: 17-120 UB: 300	LB: 17-120 UB: 360	0	ND	0	0	0
Recovered U to Storage (MT/yr)	0	2,500	2,460	4,500	0	ND	0	0	0

TABLE S.3-1—*Comparative Summary of Programmatic Alternatives (Steady-State 200 Gigawatts of Electricity)(continued)*

Case Description	No Action (Once-Through Fuel Cycle)	Fast Reactor Recycle Alternative	Thermal/ Fast Reactor Recycle Alternative	Thermal Reactor Recycle Alternative			Thorium Alternative (Once- Through Fuel Cycle)	HWR or HTGR Alternative (Once-Through Fuel Cycle)	
				Option 1—Thermal Recycle in LWRs	Option 2—Thermal Recycle in HWRs	Option 3—Thermal Recycle in HTGRs		All HWR	All HTGR
Waste Management Metrics									
Volume of SNF to repository, m^3/yr	1,950	0	0	0	750	ND	920	2,250	5,200-29,900[d]
Volume of Processing Wastes Classified as HLW to repository (m^3/yr)[e]	0	LB: 50-120 UB: 1840	LB: 50-110 UB: 1810	LB: 64 UB: 1,740	LB: ND; UB: 600-1,600	ND	0	0	0
Volume of GTCC Waste from processing (m^3/yr)[e]	0	LB: 390-420 UB: 13,700	LB: 370-390 UB: 13,200	LB: 340 UB: 13,400	LB: 240 UB: ND	ND	0	0	0
Volume of Low-Level Waste from processing (m^3/yr)[e]	0	LB: 120-420 UB: 76,300	LB: 100-320 UB: 68,800	LB: 34 UB: 52,000	ND[f]	ND	0	0	0
Thermal Load Reduction Factor (relative to No Action)	1	235	235	1.8	1.6	ND	2.0	0.9	1.4
Radiotoxicity Reduction - Time to Decay to Natural U Ore Radiotoxicity (Yr)	240,000	375	400	55,000	ND	ND	525,000	255,000	85,000

Note: LWR = light water reactor; UOX = uranium oxide (fuel); HWR = heavy water reactor; HTGR = high temperature gas-cooled reactor; ThOX = thorium oxide (fuel); GWe = gigawatts electric; ARR = advanced recycling reactor; DUPIC = Direct Use of Spent Pressurized Water Reactor Fuel in CANDU; GWd/MTHM = gigawatt days per metric ton of heavy metal; ND = no data; U = uranium; LEU = low enriched uranium; MOX = mixed-oxide (fuel); MT/yr = metric tons per year; TRU = transuranics; SNF = spent nuclear fuel; Cs = cesium; Sr = strontium; LB= lower bound; UB = upper bound; m^3/yr = cubic meters per year; GTCC = Greater-than-Class-C low-level radioactive waste.

[a] 200 GWe is the power production, not the installed capacity. Reactor capacity factors (i.e., the percentage of time that the reactor is producing power) less than 100 percent means that the installed capacity of the reactors must be greater than 200 GWe. Typical values are 90 percent or higher for LWRs and 80 to 85 percent for fast reactors.

[b] Mass listed is only for the remaining heavy metal and the fission products in the spent fuel; no hardware or cladding is included. The fuel cladding and assembly hardware are included in the waste volume estimates for GTCC LLW in the Table, as appropriate.

[c] Wigeland 2008c provides a range of waste quantities from reprocessing of spent LWR fuel, which results in the lower bound and upper bound estimates for cesium and strontium waste volumes.

[d] The lower value represents the volume of the fuel compacts after separation from the graphite hexagonal prismatic blocks; the higher value represents the volume of spent fuel assuming that the fuel compacts are still in the graphite hexagonal prismatic blocks.

[e] Waste volume estimates are presented as a range to reflect current uncertainty associated with waste forms, decay storage, waste categorization, volume reduction, and other factors. The ranges presented are estimates of the potential minimum and maximum quantities in light of these uncertainties. In some cases, insufficient data exist to estimate the lower or upper bound values. This PEIS analysis is based on the highest volume estimate for each waste category.

[f] LLW waste generation is estimated at 5,180 m^3/yr. Since it is not known whether this represents an upper or lower bound, or represents an expectation based on recent results, this value is not listed in the table.

S.4 ENVIRONMENTAL IMPACTS OF DOMESTIC ALTERNATIVES

This GNEP PEIS analyzes and compares the potential environmental impacts associated with the current U.S. commercial nuclear fuel cycle and implementation of alternative nuclear fuel cycles. As a result, the analysis is necessarily long-term, focusing on the potential impacts that could result from implementing each of the programmatic alternatives over many decades. It is not possible to predict with confidence when any of the action alternatives would be implemented in their entirety, as many factors would affect the success of implementing any alternative, including market forces, public policy, the costs and timing for transition to and implementation of the alternatives, and regulatory issues. Based on cautious but reasonable assumptions, this PEIS considers that transition to, and complete implementation of any action alternative could be achieved in the 2060-2070 time frame.

This PEIS analyzes four different growth rates for electricity generation from nuclear power (0 or no growth, 0.7 percent, 1.3 percent and 2.5 percent for a high growth rate case). Unless indicated otherwise, the environmental impact analysis in this Summary is presented for a 1.3 percent growth scenario (which would equate to approximately 200 gigawatts of electricity) from nuclear power in the 2060–2070 time frame. While it is recognized that there are other potential combinations, the scenarios analyzed provide a reasonably foreseeable range of future conditions.

Many of the environmental consequences associated with the alternatives vary directly with the electricity production. For example, if the future electricity production by nuclear reactors at full implementation is 400 gigawatts instead of 200 gigawatts, the number of reactors associated with any alternative could double. Many other factors, such as the annual amount of spent nuclear fuel generated, the annual quantities of wastes generated and the annual radiological emissions from facilities, could be scaled in a similar manner.

For any programmatic alternative, there are a large number of reactor scenarios that could be used to represent a national nuclear power generating system, and thus to estimate environmental impacts for the four scenarios. For example, to achieve an electricity production of 200 gigawatts, an alternative could include 200 reactors, each producing 1,000 megawatts or 400 reactors each producing 500 megawatts. Instead, to simplify the analysis, environmental impacts are estimated based on achieving an electricity production level rather than the number of reactors.

DOE, in this PEIS, evaluates the environmental impacts from the construction and operation of various facilities, including reactors, spent fuel processing and fuel fabrication facilities through approximately 2060–2070. For all programmatic alternatives, the analysis of impacts relies on the following common approach:

– Existing U.S. nuclear capacity is approximately 100 gigawatts of electric capacity.

– Nuclear electricity capacity would grow to approximately 200 gigawatts by the 2060–2070 time frame.

– The first new light water reactor would come on-line in approximately 2015.

– Conversion to new fuel types, if applicable, would begin in approximately 2020, and new reactors would operate using the new fuel. The 104 existing reactors would continue to operate on the typical uranium-dioxide fuel.

– Retirement of existing light water reactors would begin in 2029, and would be replaced by the same amount of nuclear generating capacity. By about the 2060–2070 time frame, all existing light water reactors would have retired or been replaced.

– New light water reactors, which are being pursued by the commercial nuclear power industry independently of DOE, could be constructed during the PEIS analysis time frame. Except for the Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative, each of the domestic programmatic alternatives would continue to need and use light water reactors. As such, for these alternatives, it is likely that any newly constructed light water reactors would continue to operate in the 2060–2070 time frame. For the Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative, this PEIS assumes that full implementation would occur by approximately 2060–2070, meaning that all light water reactors would be phased-out by that time. However, because it is possible that some light water reactors could continue to operate past 2060–2070 for the Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative, the PEIS also discusses how impacts would change if that were to occur.

– Quantities of spent nuclear fuel and radioactive wastes are based on generation from approximately 2010 through approximately 2060–2070.

Sections S.4.1 through S.4.9, which follow, present a summary comparison of the domestic programmatic alternatives. The alternatives are compared in the following areas: facility and resource requirements, quantities of spent nuclear fuel and wastes generated, occupational and public health impacts, facility accidents, intentionally destructive acts, transportation impacts, cumulative impacts, unavoidable impacts and irreversible and irretrievable impacts. Tables S.4-1 and S.4-2 present a comparative summary of the impacts of the domestic fuel cycle alternatives. Table S.4-1 presents the annual impacts once implementation is achieved in approximately 2060–2070. Table S.4-2 presents the cumulative impacts over the entire implementation period (2010 to approximately 2060–2070).

In general, given the broad, programmatic nature of the analyses, the PEIS presents impacts to certain resources such as land use, socioeconomics, air quality and visual resources which do not discriminate significantly among the alternatives. Water usage varies, but only at the fuel cycle level; that is, water usage among the open or closed fuel cycle alternatives does not vary, but usage is higher under the closed fuel cycle alternatives. In addition, the PEIS (Chapter 4, Section 4.1) examines impacts that would be common to each of the domestic programmatic alternatives, with a focus on the impacts from uranium mining, uranium enrichment, uranium fuel fabrication, low-level radioactive waste disposal and continuation of the Advanced Fuel Cycle Initiative—none of which vary significantly among the alternatives. Given the above, this Summary presents the potential impacts to those resources that tend to offer a means to discriminate among the alternatives.

TABLE S.4-1—*Comparison of Domestic Programmatic Alternatives for 200 GWe (Annual Impacts at Steady-state Endpoint)*

Alternative	SNF to repository		HLW to repository	GTCC LLW to disposal	Cs/Sr to disposal (Note 1)	LLW to disposal (Note 2)	Normal Operation Worker Impacts	Annual Number of Radiological Shipments [a]		Transport Worker Loading/ Handling Impacts (Truck)	Transport Worker Loading/ Handling Impacts (Truck/ Rail)	In-Transit Impacts (Truck)	In-Transit Impacts (Truck/ Rail)
	MTHM/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	m^3/yr	LCFs/yr	(Truck)	(Truck/ Rail)	LCFs/yr	LCFs/yr	LCFs/yr	LCFs/yr
No Action	4,340	1,950	0	0	0	LB: 4,200 UB: 15,800	13	3,410	1,000	1	0	1	0
Fast Reactor Recycle	0	0	1,840	13,700	LB: 17-120 UB: 300	LB: 4,300 UB: 92,100	15	14,800	4,590	3	3	6	1
Thermal/Fast Reactor Recycle	0	0	1,810	13,200	LB: 17-120 UB: 300	LB: 4,300 UB: 84,600	15	17,600	5,680	3	2	7	1
Thermal Recycle (Option 1)	0	0	1,740	13,400	LB: 17-120 UB: 360	LB: 4200 UB: 67,800	14	17,700	5,270	3	1	7	1
Thermal Recycle (Option 2)	3,600	750	1,600	240	0	LB: 4,200 UB: 15,800	15	8,490	2,440	2	1	4	0
Thermal Recycle (Option 3)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thorium	2,050	920	0	0	0	LB: 4,200 UB: 15,800	13	4,860	1,380	1	0	2	0
HWR/HTGR (all-HWR Option)	10,600	2,250	0	0	0	LB: 4,200 UB: 15,800	13	13,900	6,960	2	0	4	0
HWR/HTGR (all-HTGR Option)	1,540	5,200- 29,900	0	0	0	LB: 4,200 UB: 15,800	13	80,000	6,780	23	3	46	0

SNF = spent nuclear fuel; HLW = high-level radioactive waste; GTCC LLW = Greater-than Class-C low-level radioactive waste; Cs/Sr = cesium/strontium; HWR = heavy water reactor; HTGR = high temperature gas-cooled reactor; MTHM = metric tons of heavy metal; m^3/yr = cubic meters per year; LCFs= latent cancer fatalities; ND = no data; LB = lower bound; UB = upper bound.
Note 2: Range of Cs/Sr waste volumes from Table S.3-1.
Note 2: LLW volumes determined based on following: open fuel cycles: 200 GWe x 21-70 m^3/yr /GWe; closed fuel cycles: 200 GWe x 21-70 m^3/yr /GWe + LLW ranges provided for recycling in Table S.3-1.
[a] Numbers rounded to three significant figures.
Source for all other data is Chapter 4 and Appendix E of the GNEP PEIS.

TABLE S.4-2—*Comparison of Programmatic Alternatives for 200 GWe (Cumulative Impacts, 50 Years of Implementation)*

Alternative	SNF to repository		HLW to repository	GTCC LLW to disposal	Cs/Sr to disposal (Note 1)	LLW to disposal (Note 2)	Normal Operation Worker Impacts (Note 3)	Number of Radiological Shipments [a]		Transport Worker Loading/ Handling Impacts (Truck)	Transport Worker Loading/ Handling Impacts (Truck/Rail)	In-Transit Impacts (Truck)	In-Transit Impacts (Truck/Rail)
	MTHM	m^3	m^3	m^3	m^3	m^3	LCFs	(Truck)	(Truck/ Rail)	LCFs	LCFs	LCFs	LCFs
No Action	158,000	70,990	0	2,500	0	LB: 150,000 UB: 585,000	455	128,000	37,000	26	14	52	1
Fast Reactor Recycle	0	0	55,000	416,500	LB: 510-3,600 UB: 9,000	LB:2,460,000 UB:2,895,000	495	854,000	206,000	106	136	313	39
Thermal/Fast Reactor Recycle	0	0	54,000	400,500	LB: 510-3,600 UB: 9,000	LB:2,232,000 UB:2,667,000	495	826,000	199,000	103	131	303	34
Thermal Recycle (Option 1)	0	0	52,000	407,500	LB: 510-3,600 UB: 10,800	LB:1,740,000 UB:2,175,000	475	978,000	246,000	133	116	359	28
Thermal Recycle (Option 2)	71,000	14,800	LB:18,000 UB:48,000	9,700	0	LB: 150,000 UB: 585,000	495	244,000	68,500	47	25	101	4
Thermal Recycle (Option 3)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thorium	109,000	48,900	0	2,500	0	LB: 150,000 UB: 585,000	455	267,000	51,500	64	17	129	1
HWR/HTGR (all-HWR Option)	280,000	59,400	0	2,500	0	LB: 150,000 UB: 585,000	455	237,000	76,600	47	12	94	1
HWR/HTGR (all-HTGR Option)	99,000	334,300-1,922,000	0	2,500	0	LB: 150,000 UB: 585,000	455	1,730,000	156,000	487	75	979	5

SNF = spent nuclear fuel; HLW = high-level radioactive waste; GTCC LLW = Greater-than-Class-C low-level radioactive waste; Cs/Sr = cesium/strontium; HWR = heavy water reactor; HTGR = high temperature gas-cooled reactor; MTHM = metric tins of heavy metal; m^3/yr = cubic meters per year; LCFs= latent cancer fatalities; ND = no data, LB = lower bound; UB = upper bound.
Note 1: Range of Cs/Sr waste volumes from Table S.3-1. Cumulative values from Chapter 4.
Note 2: Range of LLW values from Chapter 4.
Note 3: Assumes that LCFs are relatively constant (6.5 LCFs/100 GWe) until 2015, then LCFs increase at 1.3% annually consistent with electricity growth; from 2020 to approximately 2060-2070, the alternatives ramp up to 200 GWe linearly, and LCFs increase linearly to the applicable steady-state worker impact endpoint for each alternative.
[a] All values rounded to three significant figures, including the sum totals.
Source for all data is Chapter 4 of the GNEP PEIS.

S.4.1 Facility and Resource Requirements

All fuel cycle alternatives would require significant quantities of natural uranium feed. The open fuel cycle alternatives (No Action Alternative, Thorium Alternative and Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative) would require the highest quantities of natural uranium feed. The All-High Temperature Gas-Cooled Reactor Option would require the highest natural uranium feed on an annual basis (about 45,600 metric tons). The closed fuel cycle alternatives would require much less natural uranium feed, the lowest of which is the Fast Reactor Recycle Alternative, which would require about 24,400 metric tons per year. The closed fuel cycle alternatives also would recover for future use approximately 2,460–4,500 metric tons of uranium yearly and about 26 to 56 metric tons of transuranics yearly, depending upon the closed fuel cycle alternative.

All alternatives would require various types of new facilities, including fuel enrichment and fuel fabrication facilities. The closed fuel cycle alternatives (Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and the Thermal Reactor Recycle Alternative [all options]) would require light water reactor spent fuel separation facilities/fuel fabrication facilities. Facilities to produce heavy water also would be required to implement the Thermal Reactor Recycle Alternative (Option 2) and the All-Heavy Water Reactor Option. Facilities to produce reactor-grade graphite also would be required to implement the Thermal Reactor Recycle Alternative (Option 3) and the All-High Temperature Gas-Cooled Reactor Option.

During operations, the facilities would use water for domestic needs, process support and to cool the reactor (primary and secondary cooling). Most of this water would not be consumed, but would be used for cooling and then discharged. Each light water reactor spent fuel separation facility would require approximately 330 million gallons per year (1.3 billion liters per year), and each reactor (1 gigawatt electric output) would use approximately 3 to 6 billion gallons per year (11 to 23 billion liters per year), mainly for heat dissipation. In arid environments, “dry” cooling towers could be utilized to reduce water requirements to approximately 195 million gallons per year (740 million liters per year).

S.4.2 Spent Nuclear Fuel and Radioactive Wastes

All programmatic alternatives would generate spent nuclear fuel and/or high-level radioactive waste that would require disposal in a geologic repository. The most radiotoxic contents of spent fuel and high-level radioactive waste are generally the actinide elements such as plutonium, and to a lesser extent, certain fission products (such as cesium and strontium). The amount of spent nuclear fuel and high-level radioactive waste created per year would vary from one alternative to another. In addition, each alternative would generate low-level radioactive waste during operations and Greater-than-Class-C low-level radioactive waste during decontamination and decommissioning following plant shutdown. The closed fuel cycle alternatives also would generate Greater-than-Class-C low-level radioactive waste during spent fuel recycling operations. Under the Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and Thermal Reactor Recycle Alternative (Options 1 and 3), it is also possible that cesium and strontium could be separated from other fission products, and then be stored for a period of time (300 years) and possibly disposed of as low-level radioactive waste.

The following spent nuclear fuel and waste streams do not have a clear path to disposal at this point:

- Spent nuclear fuel in quantities greater than the limit established by law for the Yucca Mountain repository
- High-level radioactive waste (including separated cesium and strontium) in quantities greater than the limit established by law for the Yucca Mountain repository
- Greater-than-Class-C low-level radioactive waste for which no disposal facilities are available
- Low-level radioactive waste in quantities that would exceed capacities of existing disposal facilities

The impact on spent nuclear fuel and high-level radioactive waste management for each alternative is evaluated by assessing: the mass/volume of spent nuclear fuel and/or high-level radioactive waste that would be sent to geologic disposal, the amount of fission products and transuranic elements requiring consolidation in waste forms that would be sent to geologic disposal, the radiotoxicity of the emplaced spent nuclear fuel and/or high-level radioactive waste and the decay heat that would have to be accommodated by the repository design. Table S.3-1 provides this information for each alternative.

Yucca Mountain Statutory Capacity Limit

Under Section 114(d) of the *Nuclear Waste Policy Act of 1982*, as amended, the Yucca Mountain repository can not accept more than 70,000 metric tons of heavy metal of spent nuclear fuel and high-level radioactive waste until such time as a second repository is in operation.

<u>Spent Nuclear Fuel Requiring Repository Disposal</u>: All alternatives would require a geologic repository. Under the No Action Alternative at the 1.3 percent growth rate, about 158,000 metric tons of heavy metal of spent nuclear fuel would be cumulatively created between 2010 and approximately 2060–2070, which is more than 2.2 times that of the **Yucca Mountain statutory capacity limit**.

Of the other alternatives, the Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and the Thermal Reactor Recycle Alternative (Option 1) would avoid direct disposal of spent nuclear fuel in a geologic repository. These alternatives, however, would produce high-level radioactive waste as part of the recycling of spent nuclear fuel.

On an annual basis at full implementation (approximately 2060-2070), the All-Heavy Water Reactor Option would generate the highest mass of spent fuel requiring geologic disposal (10,600 metric tons of heavy metal per year). For the once-through fuel cycles, the All-High Temperature Gas-Cooled Reactor Option could generate the least mass of spent fuel requiring geologic disposal (1,540 metric tons of heavy metal per year).[12] This reflects the higher burnup of high temperature gas-cooled reactors compared to the lower burnup of heavy water reactors. The Thorium Alternative would generate approximately 2,050 metric tons of heavy metal per year of spent nuclear fuel. As a point of comparison, the No Action Alternative would generate

[12] While the mass of spent nuclear fuel can be relatively smaller with the HTGR, if the spent fuel compacts are not removed from the graphite blocks, the volume of spent nuclear fuel can be substantial (see Table S.3-1).

approximately 4,340 metric tons of heavy metal per year. The total quantities generated between 2010 and approximately 2060–2070 for each alternative reflect the time-phased implementation of each alternative. For example, under the All-Heavy Water Reactor Option, no heavy water reactor spent fuel would be generated until after the initial facilities begin to operate in 2020. From that time, the amount of heavy water reactor spent fuel generated would continue to increase annually to about 10,600 metric tons of heavy metal per year, until full implementation is reached in approximately 2060–2070.

Processing Wastes Classified as High-Level Radioactive Waste Requiring Repository Disposal: The Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and the Thermal Reactor Recycle Alternatives (all options) would generate processing wastes that would be classified as high-level radioactive waste in the amount of about 50 to 1,840 cubic meters per year (65 to 2,400 cubic yards per year). The recycling of the spent fuel that would occur under these alternatives could generate approximately 50,000 cubic meters (71,500 cubic yards) of high-level radioactive waste between 2010 and approximately 2060-2070.

There are several options for encapsulating the waste in forms suitable for geologic disposal, such as in borosilicate glass, as is planned for some DOE defense-related wastes. The cladding and assembly hardware recovered at the processing plant have been included in the estimated quantity of Greater-than-Class-C low-level radioactive waste. The values listed in Table S.3-1 are estimates based on existing technologies and the best available information for encapsulating both transuranics and fission products.

As shown on Table S.3-1, the amount of transuranic radionuclides also varies among the alternatives. The Fast Reactor Recycle Alternative and Thermal/Fast Reactor Recycle Alternative would generate the lowest amount of transuranic radionuclides (0.20 to 0.22 metric tons per year) that would have to be sent to a repository for disposal. The Thorium Alternative (15.6 metric tons per year), Thermal Reactor Recycle Alternative (Option 1) (16.6 metric tons per year), Thermal Reactor Recycle Alternative (Option 2) (30 metric tons per year) and the All-High Temperature Gas-Cooled Reactor Option (32 metric tons per year) are the next lowest generators of transuranic radionuclides (either in high-level radioactive waste and/or in spent fuel that would have to be sent to a geologic repository). The No Action Alternative and the All-Heavy Water Reactor Option produce relatively large quantities of transuranic radionuclides (56 and 76 metric tons per year, respectively) in spent fuel that would have to be sent to a geologic repository.

Other Wastes: Compared to the open fuel cycle alternatives, recycling spent fuel generates much higher quantities of Greater-than-Class-C low-level radioactive waste and low-level radioactive waste, as well as potentially producing separated cesium and strontium waste (Table S.3-1). The Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative, and Thermal Reactor Recycle Alternative (Option 1) would generate relatively large quantities of Greater-than-Class-C low-level radioactive waste (more than 13,000 cubic meters per year in the peak year of operation) or about 400,000 cubic meters (520,000 cubic yards) from the spent fuel generated between 2010 and approximately 2060-2070.

The *Low-Level Radioactive Waste Policy Amendments Act* of 1985 assigns the responsibility for the disposal of Greater-than-Class-C low-level radioactive waste that results from activities licensed by the Nuclear Regulatory Commission to the Federal government (DOE), and specifies that this waste must be disposed of in a facility licensed by the Nuclear Regulatory Commission. There are no facilities licensed by the Nuclear Regulatory Commission for the disposal of Greater-than-Class-C low-level radioactive waste, and therefore this waste would remain in storage until a disposal facility can be developed.[13]

If cesium and strontium wastes are stored for approximately 300 years, their radioactivity levels would have decayed sufficiently so that these wastes potentially could be disposed of as low-level radioactive waste. Another option would be to store these wastes for eventual disposal as high-level radioactive waste in a geologic repository. About 24 metric tons per year of cesium and strontium wastes could be generated for the Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and Thermal Reactor Recycle Alternative (Options 1 and 3).

The programmatic alternatives that recycle spent fuel also would generate relatively large quantities of low-level radioactive waste compared to the open fuel cycle alternatives. The Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative, and Thermal Reactor Recycle Alternative (Option 1) would generate approximately 1.7 million to 2.9 million cubic meters (2.2 to 3.8 million cubic yards) from 2010 to approximately 2060–2070.

S.4.3 Human Health

In this PEIS, DOE estimates the health and safety impacts to workers and the public that could occur during construction and operation of facilities under each domestic alternative. These impacts include those that could occur 1) to workers from hazards common to similar industrial settings and excavation operations, such as falling or tripping (referred to as industrial hazards), 2) to workers as a result of radiation exposure during their work activities and 3) to the public from airborne releases of radionuclides. DOE concluded, based on analysis in the PEIS (see Appendix C), that adverse occupational impacts from industrial hazards would be expected to be low and would not vary among the alternatives.

To estimate potential radiological impacts, DOE used actual information from commercial nuclear plants and preliminary design information for other reactors and spent nuclear fuel recycling facilities. For impacts to workers, DOE used actual worker doses to estimate the collective dose (expressed as person-rem) to the workforce considered for each programmatic alternative. For impacts to the public, DOE used projected airborne radioactive releases from routine operations of facilities associated with each of the alternatives to estimate collective dose to the population, and the dose to the maximally exposed member of the public. Dose was then converted to latent cancer fatalities to the population, or to an increased risk of contracting a fatal cancer to the **maximally exposed individual**.

Maximally Exposed Individual

A hypothetical member of the public at a fixed location who, over an entire year, receives the maximum effective dose equivalent (summed over all pathways) from a given source of radionuclide releases to air.

[13] DOE is currently preparing an Environmental Impact Statement to evaluate a range of reasonable alternatives for disposal of Greater-than-Class-C low-level radioactive waste (see Chapter 1, Section 1.3.7).

Because the location of any new commercial facility can not be known with certainty, DOE estimated impacts to the public at six hypothetical sites. DOE developed these sites using offsite population (50 mile [80 kilometer]) and meteorological information from existing commercial reactor facilities. A combination of population and meteorological data was chosen to develop a range of conditions from generally favorable (large atmospheric mixing and small population) to unfavorable (small atmospheric mixing and large population). For this reason, the six hypothetical sites represent the range of dose and health impacts to the population that would be found at most locations that might house either separations facilities or reactors. The health effects identified in this PEIS analysis are for the operational period (2010 through approximately 2060–2070) only. By reducing the volume, thermal output, and/or radiotoxicity of spent fuel and high-level radioactive wastes requiring geologic disposal, there is also a potential to reduce long-term health impacts from such disposal.

S.4.3.1 *Impacts to Workers*

All domestic programmatic alternatives could affect worker health through direct radiation exposure. Table S.4-3 presents annual impacts to the involved (radiation) workers for each of the domestic programmatic alternatives. As shown in that table, reactor operation doses were assumed to not vary among reactor technologies.[14] As shown in Table S.4-3, there would be slightly higher impacts to workers for the closed fuel cycle alternatives than the open fuel cycle alternatives. These higher impacts are due to the additional worker doses associated with recycling. Additionally, the closed fuel cycle alternatives that recycle the highest quantities of spent fuel would result in the highest worker doses.

There also would be impacts to workers due to the storage of spent fuel and/or radioactive wastes. For the No Action Alternative, doses from storing the cumulative quantity of spent fuel that would be generated during the implementation period (approximately 158,000 MTHM of spent fuel) for 50 years at the reactor sites prior to geologic disposal was estimated at 140 person-rem, or less than 3 person-rem per year. Doses from the other open fuel cycle alternatives would be expected to vary according to the quantity of spent fuel in storage, and to range from approximately 90 person-rem to 250 person-rem. For the closed fuel cycle alternatives, the doses from the recycling facilities would include storage of radioactive wastes. Doses from such storage were not estimated for the cumulative quantities of wastes that would be generated, but these impacts are expected to be less than or similar to the spent fuel storage impacts, as these waste would generally produce smaller radiation doses. Therefore, worker doses due to storage are not expected to vary significantly among alternatives, and are expected to be much lower than doses due to reactor operations or recycling facility operations.

[14] In 2006, the average dose to a radiation worker at a Light Water Reactor in the United States was approximately 190 mrem (NRC 2007l). This average dose to a radiation worker falls within the range of doses to radiation workers at Heavy Water Reactors in Canada (Health Canada 2008). This average dose represents the best estimate of the dose to a radiation worker for the other reactor technologies.

TABLE S.4-3—*Annual Impacts to Workers for Domestic Programmatic Alternatives*

Alternative	Annual Dose from Reactor Operations (person-rem)	Annual Dose from Recycling Facility Operations [a] (person-rem)	Annual Latent Cancer Fatalities from All Facility Operations
No Action	20,900	0	13
Fast Reactor Recycle	20,900	4,600	15
Thermal/Fast Reactor Recycle	20,900	4,400	15
Thermal Reactor Recycle (Option 1)	20,900	3,300	14
Thermal Reactor Recycle (Option 2)	20,900	4,600	15
Thermal Reactor Recycle (Option 3)	No Data	No Data	No Data
Thorium	20,900	0	13
All-Heavy Water Reactor Option	20,900	0	13
All-High Temperature Gas-Cooled Reactor Option	20,900	0	13

[a] Doses from recycling facility operations differ because of worker differences among the closed fuel cycle alternatives.

S.4.3.2 *Impacts to the Public*

All domestic programmatic alternatives could affect public health through the release of radiological materials to the environment. The PEIS analyzes the impacts to both the maximally exposed individual, as well as the population within 50 miles (80 kilometers) of a facility. The analysis indicates that releases from spent nuclear fuel recycling facilities would generally cause the highest doses. As a result, the alternatives that involve spent nuclear fuel recycling would be expected to result in the highest doses to the public. However, DOE estimates that all alternatives would result in less than 1 latent cancer fatality per year to the populations surrounding the six hypothetical sites. Additional information may be found in Chapter 4 of the PEIS.

S.4.4 Facility Accidents

Each of the domestic programmatic alternatives could impact public and worker health in the event of an **accident**. An accident can be initiated by **external events**, **internal events** or **natural phenomena**. External initiators originate outside a facility and affect the facility's ability to confine radioactive material. External initiators include human-induced events, such as: aircraft crashes, external fires and explosions and natural phenomena, such as seismic disturbances and extreme weather conditions. Internal initiators occur inside a facility and include human errors, equipment failures or combinations of the two.

Accident

An unplanned event or sequence of events that results in undesirable consequences.

DOE considered a spectrum of accidents, including low consequence/high **probability** events and high consequence/low probability events. These accidents were chosen by defining a

> **Internally, Externally, and Natural Phenomena Initiated Accidents**
>
> This PEIS considers accidents that are internally, externally, and natural phenomena initiated. Internally initiated accidents are associated with a specific reactor design. These accidents could include events like failure of a reactor coolant pump, operator error, or loss of coolant. Externally initiated accidents are location-dependent and could be caused by an event such as an aircraft crash. Natural phenomena are typically location-dependent and include events such as earthquakes and tornadoes. Externally and natural phenomena initiated events are analyzed by the use of consistent release parameters regardless of the reactor design or generic location in order to provide a common basis for comparison.
>
> Externally and natural phenomena initiated accidents, which are described and the results presented in Appendix D, are generally the highest consequence accidents. Externally and natural phenomena accidents have the potential to mask any differences between reactor technologies and are most useful in providing a basis of comparison for core inventory (i.e., ultimate consequences).

bounding set of conditions such that any reasonably foreseeable accidents that could occur under the alternatives would be expected to have smaller consequences and/or risks. In this PEIS, DOE analyzed accident scenarios involving different types of reactors and nuclear fuels and those associated with nuclear fuel recycling facilities. Each scenario was analyzed using population and environmental characteristics from the six hypothetical sites. Results presented here are for the hypothetical site with the highest population and least favorable meteorological conditions (i.e., conditions that result in minimal dispersion of the radioactive material, thereby increasing the dose to individuals in the path of the plume). For each accident scenario, the PEIS includes the probability of that accident occurring during each year of reactor or facility operation, the potential consequences to the population and a maximally exposed individual if the accident were to occur (expressed as latent cancer fatalities) and the increased risk (probability multiplied by consequence) of those latent cancer fatalities. Accident analysis without a reactor design and specific site location gives results that could be misleading. The use of these results should be interpreted as providing a general range of impacts. Any reactor that would be proposed would be required to meet current Nuclear Regulatory Commission licensing and safety requirements regardless of the technology proposed. The Nuclear Regulatory Commission has approved four advanced reactor designs and is evaluating others.

> **Probability and Frequency**
>
> The probability of an accident occurring is expressed as a number between 0 (no chance of occurring) and 1 (certain to occur). Alternatively, instead of probability of occurrence, one can specify the frequency of occurrence (e.g., once in 200 years, which also can be expressed as 0.005 times per year) (DOE 2006p).

Table S.4-4 presents the estimated **frequencies**, consequences and risks from those internally initiated accidents having the highest consequences to the public. Table S.4-5 also presents the estimated frequencies, consequences and risks, but for those internally initiated accidents having the highest risks to the public. Chapter 4 and Appendix D of the PEIS provide additional information regarding the accident scenarios and their analysis, as well as the impacts to workers. Differences in the results among the various reactors are primarily due to differences in the assumed fuel and reactor designs. Another factor is the difference in assumed reactor electricity generation rates (reactor power level). For example, the light water reactor power level is nearly 10 times greater than the power level of the high temperature gas-cooled reactor.

The highest consequence, and highest risk, internally-initiated accident involving light water reactors using mixed oxide fuel (or, similarly, low enriched uranium fuel) is a scenario in which there is a direct loss of coolant because the primary coolant system overpressurizes other systems, and radionuclides are released to the atmosphere. DOE estimates that this accident, which has a probability of occurrence of about 7 in 100 million per year (i.e., frequency of about 7×10^{-8}/yr), would result in an estimated 40,000 additional latent cancer fatalities to the surrounding population of 8.2 million. These consequences are consistent with the results of the NRC's *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, NUREG-1150 (NRC 1990) and the *Surplus Plutonium Disposition Final Environmental Impact Statement*, DOE/EIS-0283 (DOE 1999d) when the high population and least favorable meteorological conditions used in this analysis are considered. The higher consequences for this accident are not the result of differences in the fuels relative to other reactors, but are instead the result of the use of high release parameters and an assumption that all containment and filter systems would fail. Therefore, although the consequences of such an accident could be large, to put such an accident into perspective, the probability of the accident should be considered. When probability is taken into account, the collective risk to the offsite population from this accident is about 2×10^{-3} to 3×10^{-3} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of about 7×10^{-8} per year of reactor operation.

The highest consequence, internally-initiated accident involving advanced light water (mixed oxide or low enriched uranium fueled) reactors is a scenario in which a relief value is opened inadvertently, thereby allowing the reactor to depressurize and the nuclear fuel rods to melt causing a release of radionuclides to the environment. DOE estimated that this accident would result in approximately 200 additional latent cancer fatalities in a population of about 8.2 million. The probability that such an accident would occur is about 1 in 100 million per year (i.e., frequency of 1.1×10^{-8}/yr). Another useful metric is risk, which takes into account the probability of an accident, and is determined by multiplying the consequences of an accident by the probability of occurrence. The internally-initiated advanced light water reactor accident with the highest risk to the public is a small loss of coolant that would occur outside of the containment structure and would be released into the reactor building. The collective risk to the offsite population for this accident is 6×10^{-6} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of 1×10^{-8} per year of reactor operation.

TABLE S.4-4—*Internally Initiated Accident with Highest Consequences to the Public (Site 6)*

Facility/Reactor—Fuel Type	Alternatives	Highest Consequence Accident (per year of operation)				
			Consequence		Risk[a]	
		Frequency (per year)	Population[b] (latent cancer fatalities)	MEI[c] (chance of contracting fatal cancer)	Population[b]	MEI[c]
Light Water Reactor—Low Enriched Uranium	All alternatives	$6.9x10^{-8}$	$4x10^{4}$	1	0.002	$7x10^{-8}$
Light Water Reactor—MOX-U-Pu	No Action[d], Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (Option 1)	$6.9x10^{-8}$	$4x10^{4}$	1	0.003	$7x10^{-8}$
Advanced Light Water Reactor—Low Enriched Uranium	All alternatives	1.1×10^{-8}	200	0.9	$2x10^{-6}$	$1 x10^{-8}$
Advanced Light Water Reactor—MOX-U-Pu	Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (Option 1)	1.1×10^{-8}	200	0.9	$2x10^{-6}$	$1 x10^{-8}$
Advanced Recycling Reactor	Fast Reactor Recycle, Thermal/Fast Reactor Recycle	0.001	0.004	$8x10^{-6}$	$4 x10^{-6}$	$8 x10^{-9}$
Heavy Water Reactor	Thermal Reactor Recycle (Option 2)[e], All-Heavy Water Reactor Option	$1x10^{-7}$	100	0.8	$1x10^{-5}$	$8x10^{-8}$
High Temperature Gas-Cooled Reactor	Thermal Reactor Recycle (Option 3)[e], All-High Temperature Gas-Cooled Reactor Option	$6.0x10^{-6}$	2	0.004	$1x10^{-5}$	$2x10^{-8}$
Thorium Light Water Reactor—Thorium/Low Enriched Uranium	Thorium	$6.9x10^{-8}$	$4x10^{4}$	1	0.002	$7x10^{-8}$
Thorium Advanced Light Water Reactor—Thorium/Low Enriched Uranium	Thorium	1.1×10^{-8}	200	0.9	$2x10^{-6}$	$1 x10^{-8}$
Nuclear Fuel Recycling Center	Fast Reactor Recycle, Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (All Options)	0.001	0.9	$8 x10^{-4}$	$9 x10^{-4}$	$8 x10^{-7}$

[a] Increased risk of a latent cancer fatality. Risk is obtained by multiplying the potential consequences and frequency of an accident.
[b] Population refers to the hypothetical site having the greatest population within 50-miles. Results are presented for the site with the highest population and least favorable meteorological conditions.
[c] MEI refers to the maximally exposed individual among the six hypothetical sites. The MEI is defined as a hypothetical individual who, because of location, activities, or living habits, could receive the maximum possible dose of radiation from a given accident.
[d] The only LWRs using MOX-U-Pu fuel in the No Action Alternative would be those reactors participating in the DOE/NNSA Surplus Plutonium Disposition Program.
[e] Use of recycled transuranics under the Thermal Reactor Recycle (Options 2 and 3) would not result in new accident scenarios and the consequences and risks are expected to be approximately the same as the values presented here, which are based on uranium fuel.

The highest consequence, and highest risk, internally initiated accident involving advanced recycling reactors is based on the published Clinch River Breeder Reactor analysis and is a scenario in which the system that extracts radioactive argon from the reactor cover gas ruptures, and radioactive gases are released to the atmosphere during reactor operation (PMC 1982). The Clinch River Breeder Reactor information assigned this accident to the unlikely frequency category with a probability of occurrence of about 1 in 1,000 per year (0.001/yr), and it would result in an estimated 0.004 additional latent cancer fatalities to the surrounding population. The collective risk to the offsite population is about 4×10^{-6} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of 8×10^{-9} per year of reactor operation.

TABLE S.4-5—*Internally Initiated Event with the Highest Accident Risks to the Public (Site 6)*

Facility/Reactor—Fuel Type	Alternative	Highest Risk Accident (per year of operation)				
			Consequence		Risk[a]	
		Frequency (per year)	Population [b] (latent cancer fatalities)	MEI [c] (chance of contracting fatal cancer)	Population [b]	MEI [c]
Light Water Reactor—Low Enriched Uranium	All alternatives	6.9×10^{-8}	4×10^{4}	1	0.002	7×10^{-8}
Light Water Reactor—MOX-U-Pu	No Action[d], Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (Option 1)	6.9×10^{-8}	4×10^{4}	1	0.003	7×10^{-8}
Advanced Light Water Reactor—Low Enriched Uranium	All alternatives	0.001	0.006	1×10^{-5}	6×10^{-6}	1×10^{-8}
Advanced Light Water Reactor—MOX-U-Pu	Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (Option 1)	0.001	0.006	1×10^{-5}	6×10^{-6}	1×10^{-8}
Advanced Recycling Reactor	Fast Reactor Recycle, Thermal/Fast Reactor Recycle	0.001	0.004	8×10^{-6}	4×10^{-6}	8×10^{-9}
Heavy Water Reactor	Thermal Reactor Recycle (Option 2)[e], All-Heavy Water Reactor Option	5×10^{-6}	10	0.06	7×10^{-5}	3×10^{-7}
High Temperature Gas-Cooled Reactor	Thermal Reactor Recycle (Option 3)[e], All-High Temperature Gas-Cooled Reactor Option	6.0×10^{-6}	2	0.004	1×10^{-5}	2×10^{-8}
Thorium Light Water Reactor—Thorium/Low Enriched Uranium	Thorium	6.9×10^{-8}	4×10^{4}	1	0.002	7×10^{-8}
Thorium Advanced Light Water Reactor—Thorium/Low Enriched Uranium	Thorium	0.001	0.006	1×10^{-5}	6×10^{-6}	1×10^{-8}
Nuclear Fuel Recycling Center	Fast Reactor Recycle, Thermal/Fast Reactor Recycle, Thermal Reactor Recycle (All Options)	0.001	0.9	8×10^{-4}	9×10^{-4}	8×10^{-7}

[a] Increased risk of a latent cancer fatality. Risk is obtained by multiplying the potential consequences and frequency of an accident.
[b] Population refers to the hypothetical site having the greatest population within 50-miles. Results are presented for the site with the highest population and least favorable meteorological conditions.
[c] MEI refers to the maximally exposed individual among the six hypothetical sites. The MEI is defined as a hypothetical individual who, because of location, activities, or living habits, could receive the maximum possible dose of radiation from a given accident.
[d] The only LWRs using MOX-U-Pu fuel in the No Action Alternative would be those reactors participating in the DOE/NNSA Surplus Plutonium Disposition Program.
[e] Use of recycled transuranics under the Thermal Reactor Recycle (Options 2 and 3) would not result in new accident scenarios and the consequences and risks are expected to be approximately the same as the values presented here, which are based on uranium fuel.

In analyzing potential heavy water reactor accidents, DOE found that the highest consequence internally initiated accident is one in which an internally initiated event causes the nuclear fuel core to melt and the containment spray system (an emergency water spray system that condenses steam in the containment and reduces radionuclide content of the vapor) fails, as do containment structures (structural barrier surrounding the reactor that contains radionuclides that may be released as a result of accidents). DOE estimates that this accident, which has a probability of occurrence of about 1 in 10 million per year (i.e., frequency of 1×10^{-7}/yr), would result in an estimated 100 additional latent cancer fatalities to the surrounding population. In contrast, DOE found that the internally initiated heavy water reactor accident with the highest risk to the public is one in which the fuel core melts, but the containment spray system and structures remain intact and effective. The collective risk to the offsite population is about 7×10^{-5} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of 3×10^{-7} per year of reactor operation.

In analyzing potential accidents involving high temperature gas-cooled reactors, DOE found that the highest consequence and highest risk internally initiated accident is one in which the reactor is depressurized by a loss of coolant (helium), and radionuclides are released to the atmosphere. DOE estimates that this accident, which has a probability of occurrence of about 6 in 1 million per year (i.e., frequency of 6×10^{-6}/yr), would result in an estimated 2 additional latent cancer fatalities to the surrounding population. The collective risk to the offsite population is about 1×10^{-5} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of about 2×10^{-8} per year of reactor operation.

The accident impacts for the thorium fueled LWR and ALWR are estimated to be the same as the low enriched uranium fueled LWR and ALWR, respectively.

In addition to reactor accident scenarios, DOE also evaluated potential accidents involving the nuclear fuel recycling center and found that the highest consequence, and highest risk, accident is one in which an explosion and fire release radionuclides to the environment. DOE estimates that this accident, which has a probability of occurrence of about 1 in 1,000 per year (i.e., frequency of 0.001/yr), would result in less than 1 additional latent cancer fatality in the surrounding population. The collective risk to the offsite population is about 9×10^{-4} latent cancer fatalities per year of operation. For the maximally exposed individual, this accident would result in an increased risk of contracting a fatal cancer of about 8×10^{-7} per year of reactor operation.

DOE also evaluated accidents initiated by external phenomena and found that an aircraft crash into a reactor containment building that causes severe damage to the fuel core and results in loss of containment, and an earthquake that causes similar damage and containment loss would have the highest consequences of any externally-initiated accident. The consequences and collective risk of these accidents, however, are less than those of the light water reactors fueled by mixed oxide or low enriched uranium fuels in which there is a direct loss of coolant because the primary coolant system overpressurizes other systems and radionuclides are released.

S.4.5 Intentional Destructive Acts

Whether acts of sabotage or terrorism would occur, and the exact nature and location of the events or the magnitude of the consequences of such acts if they were to occur, are inherently uncertain. Nevertheless, DOE estimated the consequences of intentional destructive acts, such as terrorism events. The analysis of intentional destructive acts differs from the accident analysis presented above in that this analysis is intended to provide an estimate of the consequences of such events, without attempting to determine a frequency associated with intentional destructive acts (DOE assumes an intentional destructive act would occur; i.e., with a probability of 1.0). Table S.4-6 summarizes the results of the analysis.

TABLE S.4-6—*Summary of Bounding Intentional Destructive Acts Scenario*

Facility	Offsite Population[a]		MEI[b]		Noninvolved Worker[b]	
	Dose (person-rem)	Latent Cancer Fatality	Dose (rem)	Latent Cancer Fatality	Dose (rem)	Latent Cancer Fatality
Light Water Reactor– Low Enriched Uranium, MOX-U-Pu, Thorium	$6x10^7$	$4x10^4$	$1x10^5$	1	$5x10^5$	1
Advanced Light Water Reactor– Low Enriched Uranium, MOX-U-Pu, Thorium	$8x10^6$	5,000	$2x10^4$	1	$2x10^5$	1
Advanced Recycling Reactor	$2x10^7$	$1x10^4$	$5x10^4$	1	$4x10^5$	1
Heavy Water Reactor	$3x10^6$	2,000	7,000	1	$6x10^4$	1
High Temperature Gas-Cooled Reactor	$1x10^6$	800	3,000	1	$3x10^4$	1
Nuclear Fuel Recycling Center	$2x10^5$	100	70	0.09	500	0.6

[a] Increased number of Latent Cancer Fatalities.
[b] Increased likelihood of a Latent Cancer Fatality.
Note: MEI = maximally exposed individual

The offsite population impacts in Table S.4-6 differ among the various reactors due in part to the differences in the amount of electricity produced (power levels) by the reactors. For example, the power level of a light water reactor is nearly 10 times greater than the power level of a high temperature gas-cooled reactor. When power level is considered, offsite population impacts are consistent among the reactors with the exception of the light water reactor.

Even after considering differences in power levels, the low enriched uranium and MOX-U-Pu fueled light water reactor offsite population impacts are still greater than the offsite population impacts for the other reactors. This is because the light water reactor results are based on an internally-initiated intentional event in which coolant is lost and higher release fractions are assumed, whereas the impacts for all other reactors are based on an aircraft crash event. The advanced light water reactor design includes safety features that make the probability of internal events (such as a catastrophic loss of coolant) remote, but the light water reactor analyzed does not include these safety features. As a result of the different events and higher release parameters, the light water reactor offsite population impacts are greater than the impacts for the advanced light water reactor. All future reactors are expected to have advanced designs that would make scenarios, such as the catastrophic loss of coolant, remote.

S.4.6 Transportation Impacts

Transportation of spent fuel, high-level radioactive waste and/or other radiological materials would be required for all alternatives. Once generated at a commercial reactor, spent nuclear fuel would be transported to a repository (for open fuel cycle alternatives) or to a recycling facility (for closed fuel cycle alternatives). Reusable materials from recycling would be fabricated into new reactor fuel, which would then be transported to the reactors, and non-reusable materials would be transported for disposal. In this PEIS, DOE evaluates the health and safety impacts to workers and the public from 1) loading and inspecting (handling) the shipping casks, 2) routine (in transit, incident-free) transportation and 3) transportation accidents (both radiological impacts and fatalities due to traffic accidents). Both all-truck transport and a combination of truck and rail transport are analyzed.

Based on a 50-year shipping campaign, the number of shipments (assuming all truck) would range from 128,000 (No Action Alternative) to 1,730,000 (All-High Temperature Gas-Cooled Reactor Option) for the open fuel cycle alternatives, and from 244,000 (Thermal Reactor Recycle Alternative (Option 2)) to 978,000 (Thermal Reactor Recycle Alternative (Option 1)) for the closed fuel cycle alternatives (Table S.4-7). The number of shipments (assuming a combination of truck and rail) would range from 37,000 (No Action Alternative) to 156,000 (All-High Temperature Gas-Cooled Reactor Option) for the open fuel cycle alternatives, and from 68,500 (Thermal Reactor Recycle Alternative (Option 2)) to 246,000 (Thermal Reactor Recycle Alternative (Option 1)) for the closed cycle alternatives (Table S.4-7).

TABLE S.4-7—*Total Number of Shipments (50 years of implementation)*

Transportation Mode	No Action	Fast Reactor Recycle	Thermal/Fast Reactor Recycle	Thermal Reactor Recycle—Option 1	Thermal Reactor Recycle—Option 2	Thorium	Heavy Water Reactor/High Temperature Gas-Cooled Reactor	
							All-Heavy Water Reactor Option	All-High Temperature Gas-Cooled Reactor Option
Truck	128,000	854,000	826,000	978,000	244,000	267,000	237,000	1,730,000
Truck and Rail [a]	37,000	206,000	199,000	246,000	68,500	51,500	76,600	156,000

[a] All shipment of fresh nuclear fuel is assumed to be via truck transport. See Table 4.8-10 for detailed breakdown of material shipments.
Note 1: All numbers rounded to three significant figures.
Note 2: Thermal Reactor Recycle Alternative (Option 3) not included due to unavailability of data.

The handling of spent fuel and other radiological materials at the various facilities could result in health and safety impacts to workers. The estimated latent cancer fatalities from the handling of truck casks (under the open fuel cycle alternatives) would range from about 26 (No Action Alternative) to 487 (All-High Temperature Gas-Cooled Reactor Option); under the closed fuel cycle alternatives from about 47 (Thermal Reactor Recycle (Option 2)) to about 133 (Thermal Reactor Recycle (Option 1)) (Table S.4-8). The estimated latent cancer fatalities from the handling of casks for truck and rail transport under the open fuel cycle alternatives would range from about 12 (All-Heavy Water Reactor Option) to 75 (All-High Temperature Gas-Cooled Reactor Option), and under the closed fuel cycle alternatives would range from about 25 (Thermal Reactor Recycle (Option 2)) to 136 (Fast Reactor Recycle Alternative) (Table S.4-9).

The estimated number of latent cancer fatalities would occur in a worker population of several hundred thousand who would be involved in these operations every year.

TABLE S.4-8—*Truck Handling Health and Safety Impacts (50 Years of Implementation for 200 Gigawatts of Electricity)*

Alternative	Handling Impacts Loading		Handling Impacts Inspection		Total	
	person-rem	LCFs	person-rem	LCFs	person-rem	LCFs
No Action	36,700	22	6,430	4	43,200	26
Fast Reactor Recycle	160,000	96	17,900	11	177,000	106
Thermal/Fast Reactor Recycle	155,000	93	17,200	10	172,000	103
Thermal Reactor Recycle-- Option 1	198,000	119	23,800	14	222,000	133
Thermal Reactor Recycle-- Option 2	67,100	40	11,100	7	78,100	47
Thorium	91,700	55	15,800	9	107,000	64
All-Heavy Water Reactor Option	67,500	40	11,700	7	79,100	47
All-High Temperature Gas-Cooled Reactor Option	693,000	416	119,000	71	812,000	487

Source: Appendix E
Note 1: All latent cancer fatalities (LCFs) rounded to nearest whole number.
Note 2: Thermal Reactor Recycle Alternative (Option 3) not included due to unavailability of data.

TABLE S.4-9—*Truck and Rail Handling Health and Safety Impacts (50 Years of Implementation for 200 Gigawatts of Electricity)*

		Handling Impacts					
		Loading		Inspection		Total	
		person-rem	LCFs	person-rem	LCFs	person-rem	LCFs
No Action	Rail	22,200	13	546	0	22,700	14
	Truck	592	0	101	0	693	0
	Total	**22,800**	**14**	**647**	**0**	**23,400**	**14**
Fast Recycle	Rail	197,000	119	10,600	6	208,000	125
	Truck	15,600	9	2,660	2	18,200	11
	Total	**213,000**	**128**	**13,300**	**8**	**226,000**	**136**
Thermal/Fast Recycle	Rail	192,000	116	10,500	6	202,000	122
	Truck	12,800	8	2,190	1	15,000	9
	Total	**205,000**	**123**	**12,700**	**8**	**217,000**	**131**
Thermal Recycle, Option 1	Rail	169,000	102	8,700	5	178,000	107
	Truck	11,700	7	2,000	1	13,700	8
	Total	**181,000**	**109**	**10,700**	**6**	**192,000**	**116**
Thermal Recycle, Option 2	Rail	36,900	22	2,780	2	39,700	24
	Truck	1,020	1	175	0	1,200	1
	Total	**37,900**	**23**	**2,950**	**2**	**40,900**	**25**
Thorium	Rail	26,100	16	632	0	26,700	16
	Truck	891	1	152	0	1,040	1
	Total	**27,000**	**16**	**784**	**0**	**27,700**	**17**
HWR	Rail	18,500	11	464	0	19,000	11
	Truck	1,500	1	257	0	1,760	1
	Total	**20,000**	**12**	**722**	**0**	**20,700**	**12**
HTGR	Rail	120,000	72	2,700	2	122,000	73
	Truck	2,620	2	447	0	3,060	2
	Total	**122,000**	**73**	**3,160**	**2**	**126,000**	**75**

Source: Appendix E
Note 1: All latent cancer fatalities (LCFs) rounded to nearest whole number.
Note 2: Thermal Reactor Recycle Alternative (Option 3) not included due to unavailability of data.

The in-transit, incident-free impacts are shown in Tables S.4-10 (truck transit) and S.4-11 (truck/rail transit) for the programmatic domestic fuel cycle alternatives. Unlike handling impacts, the in-transit impacts are dependent on the distance that material would be transported, the specific routes that would be utilized and the population densities along those routes. Of these factors, the transport distance is the most significant factor, and for this PEIS, DOE based this distance on the average distance used in previous DOE *National Environmental Policy Act* documents involving the disposal of spent nuclear fuel and high-level radioactive waste (about 2,100 mi [3,380 km]).

TABLE S.4-10—*Summary of In-Transit, Truck Transportation Impacts (50 Years of Implementation for 200 Gigawatts of Electricity)*

Alternative	In-Transit Impacts				Incident-Free LCFs	Accident Impacts		
	Crew		Public					
	person-rem	LCFs	person-rem	LCFs		person-rem	LCFs	Collision Fatalities
No Action	14,900	9	71,300	42	52	1.37	0	11
Fast Recycle	151,000	90	371,000	222	313	51.6	0	73
Thermal/Fast Recycle	146,000	87	360,000	216	303	41.0	0	71
Thermal Recycle—Option 1	157,000	94	441,000	265	359	2.97	0	84
Thermal Recycle—Option 2	31,000	19	137,000	82	101	1.23	0	21
Thorium	36,300	22	179,000	107	129	0.881	0	23
HWR	26,600	16	130,000	78	94	0.597	0	20
HTGR	271,000	162	1,360,000	816	979	0.592	0	149

Source: Appendix E
Note 1: All latent cancer fatalities (LCFs) rounded to nearest whole number.
Note 2: Thermal Reactor Recycle Alternative (Option 3) not included due to unavailability of data.

TABLE S.4-11—*Summary of In-Transit, Truck and Rail Transportation Impacts (50 Years of Implementation for 200 Gigawatts of Electricity)*

		In Transit Impacts (Note 1)				Total Incident-Free LCF's	Accident Impacts		
		Crew		Public					
		person-rem	LCFs	person-rem	LCFs		person-rem	LCFs	Collision Fatalities
No Action	Rail	420	0	1,240	1	1	0.0828	0	1
	Truck	36.3	0	183	0	0	0	0	2
	Total	**456**	**0**	**1,430**	**1**	**1**	**0.0828**	**0**	**3**
Fast Recycle	Rail	4,670	3	24,100	14	17	10.4	0	10
	Truck	5,940	4	29,990	18	22	0.487	0	5
	Total	**10,600**	**6**	**54,100**	**32**	**39**	**10.9**	**0**	**15**
Thermal/Fast Recycle	Rail	4,540	3	23,500	14	17	8.26	0	10
	Truck	4,710	3	24,400	15	17	0.382	0	5
	Total	**9,250**	**6**	**42,300**	**25**	**34**	**8.64**	**0**	**15**
Thermal Recycle, Option 1	Rail	4,070	2	22,200	13	16	0.345	0	10
	Truck	855	1	20,100	12	13	0	0	9
	Total	**4,920**	**3**	**42,300**	**25**	**28**	**0.345**	**0**	**19**
Thermal Recycle, Option 2	Rail	940	1	4,950	3	4	0.130	0	2
	Truck	62.7	0	316	0	0	0	0	4
	Total	**1,010**	**1**	**5,260**	**3**	**4**	**0**	**0**	**6**
Thorium	Rail	487	0	1,420	1	1	0.0561	0	1
	Truck	62.9	0	317	0	0	0	0	3
	Total	**550**	**0**	**1,740**	**1**	**1**	**0.0561**	**0**	**4**
HWR	Rail	358	0	1,080	1	1	0.0407	0	0
	Truck	92.3	0	466	0	0	0	0	6
	Total	**450**	**0**	**1,540**	**1**	**1**	**0.0407**	**0**	**6**
HTGR	Rail	2,090	1	5,660	3	5	0.0361	0	3
	Truck	160	0	809	0	1	0	0	10
	Total	**2,250**	**1**	**6,470**	**4**	**5**	**0.0361**	**0**	**13**

Source: Appendix E.
Note 1: All latent cancer fatalities (LCFs) rounded to nearest whole number.
Note 2: Thermal Reactor Recycle Alternative (Option 3) not included due to unavailability of data.

As shown on Tables S.4-10 and S.4-11, truck and rail transport would result in smaller impacts than truck transport because there are fewer total shipments, which results in fewer total miles, which in turn results in lower exposures to workers (referred to as 'crew') and the public. Additionally, and for the same reasons, the number of fatalities (collisions) due to traffic accidents would be lower for the combination truck and rail transport.

For truck transport, the All-High Temperature Gas-Cooled Reactor Option would have the highest transportation impacts (incident-free and traffic fatalities), primarily due to the large number of shipments of spent fuel (more than 1.7 million shipments, as shown in Table S.4-7). This relatively large number of shipments is caused primarily by the large volume of spent fuel associated with the graphite blocks in high temperature gas-cooled reactors. The Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and Thermal Reactor Recycle Alternative (Option 1) would have the next highest impacts.

As shown on Table S.4-11, for truck and rail transport, the Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and Thermal Reactor Recycle Alternative (Option 1) would have the highest expected transportation impacts. For truck and rail transport, these closed fuel cycle alternatives would have the most shipments, the highest handling impacts, and the highest in-transit impacts.

The reason why the All-High Temperature Gas-Cooled Reactor Option would not have the highest transportation impacts for truck and rail transport is because the packaging of spent nuclear fuel potentially could allow for a reduction in the number of spent fuel shipments by a factor of approximately 45 (from 1,560,000 truck shipments of spent fuel to 33,000 rail shipments of spent fuel). By contrast, the transportation impacts of the closed fuel cycle alternatives (with the exception of the Thermal Reactor Recycle Alternative (Option 2)) are dominated by Greater-than-Class-C low-level radioactive waste shipments. When packaged for rail transportation, these waste shipments, while reduced compared to truck transport, would remain large.

Transportation accidents, some of which could potentially breach the shipping container, are represented by a spectrum of accident severities and releases of radioactive material. Two types of analyses were performed. The first analysis takes into account the probabilities and consequences of a spectrum of potential accident severities. For the spectrum of accidents considered in the analysis, accident consequences in terms of collective dose to the population within 50 mi (80 km) were multiplied by the accident probabilities to yield collective dose risk to the population (person-rem), which were converted to latent cancer fatalities (see Tables S.4-10 and S.4-11). From a risk perspective, the truck or combination of truck and rail shipping campaigns would not be expected to result in a latent cancer fatality in the affected population.

DOE also analyzed the maximum reasonably foreseeable accident, which is a long-duration, high-temperature fire event that engulfs the entire cask, and whose probability of occurrence is about 1 in 10 million. This accident scenario would involve spent nuclear fuel from high temperature gas-cooled reactors or light water reactors, or MOX-U-Pu spent fuel. DOE found there would be approximately 1 latent cancer fatality in an urban area.

S.4.7 Cumulative Impacts

As defined by the Council of Environmental Quality regulations implementing the procedural provisions of NEPA, cumulative impacts are “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions.” The regulations further explain that “cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time” (40 CFR 1508.7).

Implementation of any of the programmatic alternatives could result in the construction and operation of hundreds of new facilities that would be located throughout the U.S. These facilities would have short-term (50-60 years) environmental impacts, and much longer-term impacts (thousands of years) as additional, future geologic disposal capacity is developed. Accordingly, in this PEIS, DOE assesses the cumulative impacts of the programmatic alternatives on various resources, such as water and land use, and the demand for materials and electricity, and on public health from transportation of radiological shipments.

DOE estimates, based on current rates of water use, that water consumption would increase to about 460 billion gallons per day (1,800 billion liters per day) by 2060. Implementation of any of the domestic programmatic alternatives would require approximately 3.3 billion gallons per day (12.2 billion liters per day), based on the use of approximately 6 billion gallons per year (24 billion liters per year) for each gigawatt of energy produced, which is about 0.7 percent of the daily water use of the U.S. Most of the water used by the alternatives would be required for cooling purposes and as much as 99 percent of the water used for this purpose would be returned to its source.

The alternatives in this PEIS would contribute to cumulative amounts of spent nuclear fuel and radioactive wastes that would require management and disposal, including: 1) spent nuclear fuel and high-level radioactive waste; 2) Greater-than-Class-C low-level radioactive waste; and 3) low-level radioactive waste. The *Nuclear Waste Policy Act* of 1982, as amended, provides for the disposal of commercial spent nuclear fuel and DOE spent nuclear fuel and high-level radioactive waste in the Nation's first proposed geologic repository to be located at Yucca Mountain, Nevada. The *Nuclear Waste Policy Act* limits the initial capacity of Yucca Mountain to 70,000 MTHM of spent nuclear fuel and high-level radioactive waste until such time as a second repository is in operation (42 U.S.C. 10101 et seq.). DOE has allocated this capacity between 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE spent nuclear fuel and high-level radioactive waste. Disposal of more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste at the Yucca Mountain site prior to completion of a second repository would require a legislative change.

In its cumulative impacts analysis, the Yucca Mountain Supplemental Environmental Impact Statement (SEIS) (DOE 2008f), issued in June 2008, evaluated the disposal of up to approximately 130,000 MTHM of commercial spent nuclear fuel,[15] equivalent to the amount projected from all existing commercial power reactors during all of their projected lifetimes. The Yucca Mountain SEIS also evaluated an alternative disposal case in which DOE would dispose of 63,000 MTHM of commercial spent nuclear fuel as spent fuel, as in the Yucca Mountain SEIS proposed action, but the balance of this commercial spent nuclear fuel inventory (approximately 67,000 MTHM) would be recycled and the resultant high-level radioactive waste would be transported to and disposed of at the Yucca Mountain geologic repository. This amount of commercial spent nuclear fuel (i.e., approximately 67,000 MTHM) also is a part of the commercial spent nuclear fuel inventory evaluated in the GNEP programmatic alternatives.

For the 200 GWe scenario, the GNEP closed fuel cycle alternatives could generate between 18,000 and 55,000 cubic meters of high-level radioactive waste that would require disposal in a geologic repository. (In addition, the Thermal Reactor Recycle Alternative (Option 2), while considered a closed fuel cycle alternative, could generate approximately 71,000 MTHM spent

[15] The Yucca Mountain SEIS cumulative impacts analysis also evaluated the disposal of all DOE spent nuclear fuel (approximately 2,500 MTHM) and all DOE high-level radioactive waste (approximately 36,000 canisters).

nuclear fuel.)[16] For the 200 GWe scenario, the GNEP open fuel cycle alternatives could generate between 99,000 and 280,000 MTHM spent nuclear fuel that would require disposal in a geologic repository.

Independent of the domestic programmatic alternatives, DOE is preparing an Environmental Impact Statement for the Disposal of Greater-than-Class-C Low-Level Radioactive Waste (DOE/EIS-0375) (72 FR 40135). DOE estimates that approximately 2,600 cubic meters of Greater-than-Class-C low-level radioactive waste will require management nationwide (72 FR 40135). In addition, DOE estimates that there will be certain wastes that will be generated from DOE activities which may not have an identified disposal path and will have characteristics similar to Greater-than-Class-C low-level radioactive waste. This DOE waste is estimated to be 3,000 cubic meters (72 FR 40135). Thus, the total Greater-than-Class-C low-level radioactive waste that will require management is projected to be 5,600 cubic meters. For the 200 GWe scenario, the GNEP closed fuel cycle alternatives could generate 9,700 to 416,500 cubic meters of Greater-than-Class-C low-level radioactive waste, while the open fuel cycle alternatives (including the No Action Alternative) could generate approximately 2,500 cubic meters. (The estimates DOE has developed for the GTCC EIS, as well as the estimates developed for the GNEP programmatic alternatives, include the quantities of Greater-than-Class-C low-level radioactive waste that would be generated from the decontamination and decommissioning of existing light water reactors.) Consequently, the closed fuel cycle alternatives would account for approximately 64 to 99 percent of the total Greater-than-Class-C low-level radioactive waste, while the open fuel cycle alternatives would account for approximately 31 percent of the total Greater-than-Class-C low-level radioactive waste.

In 2005 and 2006, the total amount of low-level radioactive waste disposed of at the three commercial disposal facilities in the United States was approximately 113,000–115,000 cubic meters annually (NRC 2007g, MIMS 2008). Of this low-level radioactive waste, in 2006, approximately 52,500 cubic meters was related to nuclear-generated electricity and 62,000 cubic meters was unrelated to nuclear-generated electricity (MIMS 2008). Assuming that low-level radioactive wastes unrelated to nuclear-generated electricity would continue at this rate, over the next 50 years, approximately 3,100,000 cubic meters of low-level radioactive waste would require disposal. For the 200 GWe scenario, the GNEP closed fuel cycle alternatives[17] could generate approximately 1,740,000–2,895,000 cubic meters of low-level radioactive waste, or approximately 36–48 percent of the total low-level radioactive waste that would require disposal**.** The open fuel cycle alternatives would generate approximately 150,000–585,000 cubic meters of low-level radioactive waste, or approximately 5–16 percent of the total low-level radioactive waste that would require disposal. As a result of recycling spent fuel, the closed fuel cycle alternatives generate much higher quantities of low-level radioactive waste. All of the estimates of low-level radioactive waste quantities assume that future reactors would generate low-level radioactive waste in quantities similar to existing commercial reactors.

With respect to radiological transportation, the Yucca Mountain SEIS (DOE 2008f) includes a detailed analysis of the cumulative transportation impacts associated with past, present and future radiological shipments (including spent nuclear fuel associated with the Yucca Mountain

16 Insufficient data exists to estimate the amount of spent nuclear fuel from the Thermal Reactor Recycle Alternative (Option 3).
17 Thermal Reactor Recycle Alternative (Option 2) not included due to lack of data for DUPIC fuel fabrication facility.

repository). That analysis includes consideration of impacts from 1943 through 2073 (which falls within the approximate endpoint for implementation (2060–2070) in this GNEP PEIS). Based on the Yucca Mountain SEIS cumulative impact analysis, DOE estimated the cumulative impacts shown in Table S.4-12.

TABLE S.4-12—*Potential Cumulative Transportation Impacts*

	Worker Dose		General Population Dose		Traffic Fatalities [a]
	person-rem	LCF	person-rem	LCF	
Collective dose and traffic fatalities of non-GNEP transportation					
Historical DOE shipments and reasonably foreseeable actions [b]	28,000	17	49,000	29	94
General radioactive material transportation (1943 to 2073) [c]	350,000	210	300,000	180	28
Yucca Mountain estimated impacts [d]	5,600–5,900	3	1,100–1,200	1	3
Subtotal of non-GNEP transportation impacts	380,000	230	350,000	210	130
GNEP Alternatives (Low values are for No Action Alternative, Truck and Rail Scenario [e]; High values are for All-HTGR Alternative, Truck Scenario[f]	450-270,000	0-160	1,540-1,400,000	1-820	3-150
Total Collective Transportation Impacts	380,000–650,000	230-390	350,000–1,800,000	210-1,000	130-280

Note: Numbers are rounded to two significant figures; therefore, totals may differ from sums.
[a] The values provided in this column represent the number of expected vehicular accident fatalities. Additional fatalities due to release of radioactive materials are less than one percent of these impacts; therefore, these are not included. For comparison, there could be 28 expected fatalities over the 131-year period (1943-2073) based on the NRC traffic fatality rate of 0.213 traffic fatalities per year from radioactive material shipments (NRC 1977b).
[b] The values provided in this row represent all known historical DOE shipments, starting in 1943 (the year operations began at the Hanford Site and Oak Ridge Reservation) and all reasonably foreseeable actions involving transportation of radioactive materials through 2073 (the assumed end date for Yucca Mountain shipments) provided in other NEPA documents. The values are based on in-transit impacts only. Table 8-14 of DOE 2008f is the source of the data provided.
[c] This row represents an estimated collective dose due to transport of eight categories of radioactive materials [1) industrial, 2) radiography, 3) medical, 4) fuel cycle, 5) research and development, 6) unknown, 7) waste, and 8) other]. The values are based on in-transit impacts only. Source: DOE 2008f, Table 8-14.
[d] Values provided represent the Yucca Mountain Supplemental EIS proposed action. The values are based on in-transit impacts only. Source: DOE 2008f, Table 8-14.
[e] The No Action Alternative, Truck and Rail Scenario represents the minimum estimated transportation impacts of the programmatic alternatives analyzed in the GNEP PEIS. The values are based on in-transit impacts only. Source: Table S.4-11
[f] The All-High Temperature Gas-Cooled Option, Truck Scenario represents the maximum estimated transportation impacts of the programmatic alternatives analyzed in the GNEP PEIS. The values are based on in-transit impacts only. Source: Table S.4-10.

The programmatic alternatives, including the No Action Alternative, could result in land disturbances of approximately 600,000 acres (243,000 hectares) for the 1.3 percent growth rate. Future land use requirements associated with population growth are projected to result in the development of an additional 52 million acres (21 million hectares) by 2060. Consequently, the land use impacts from the alternatives would account for less than a 1.5 percent increase compared to the land use associated with population growth.

The alternatives in this PEIS could have a beneficial impact on air quality and greenhouse gas emissions as nuclear power generation of electricity could replace a similar amount of fossil fuel generation of electricity. For every gigawatt of electricity produced by nuclear power, approximately 2,000,000 metric tons of carbon dioxide (conventional coal plant) or 1,000,000 metric tons of carbon dioxide (conventional natural gas plant) would not be emitted to the atmosphere.

The alternatives in this PEIS could result in the construction of more than 200 nuclear facilities over an approximate 50-year period for the 1.3 percent growth rate scenario. Based on the construction requirements of a typical 1,000 megawatt electric nuclear plant on an annual basis, these new nuclear facilities would use approximately 600,000 metric tons of steel and 3.4 million metric tons of concrete. Compared to the current usage of steel and concrete, these increases would amount to less than 1 percent (steel) and 2.8 percent (concrete). Of course, construction of fossil fuel burning plants or even alternative energy plants to produce a similar amount of electricity as a nuclear option would also use a substantial amount of construction resources.

S.4.8 Unavoidable Adverse Impacts

All of the domestic programmatic alternatives would result in unavoidable adverse impacts. For the 1.3 percent growth scenario, the construction and operation of nuclear facilities would disturb up to 600,000 acres (242,000 hectares) of land, use approximately 3 to 6 billion gallons (12 to 24 billion liters) of water annually per gigawatt of capacity, and expose workers and the general public to radiation from the nuclear facilities and from the transportation of radiological materials. Each alternative also would generate spent nuclear fuel and/or other radioactive wastes that would require transportation and management for long periods of time, which for some waste types would last for thousands of years and would require additional geologic repository capacity.

S.4.9 Irreversible and Irretrievable Resource Commitments

Under all alternatives, construction and operation of new facilities would cause a short-term commitment of resources (such as concrete, steel, and water), and would permanently commit certain other resources, such as land. Losses of terrestrial and aquatic habitats from natural productivity to accommodate new facilities and temporary disturbances required during construction would occur. Land clearing and construction activities would disperse wildlife and temporarily eliminate habitats. Although some destruction would be inevitable during and after construction, these losses would be minimized by selection of mitigation measures developed through environmental reviews at the site-specific level.

S.4.10 Preferred Alternative

The Council on Environmental Quality regulations require an agency to identify its preferred alternative or alternatives, if one or more exists, in a draft EIS (40 CFR 1502.14(e)). DOE's preference is to close the fuel cycle. DOE has not determined which of the specific closed fuel cycle alternatives is preferred, but will do so in the Final PEIS.

Recycling spent fuel could include the destruction and use of the transuranic materials in the spent fuel, thereby significantly reducing the thermal output and radiotoxicity of wastes requiring geologic disposal. The analysis shows that recycling spent fuel could reduce the time period required for the radiotoxicity of the wastes to fall to that of natural uranium ore from approximately 240,000 years (for the No Action Alternative) to 1,000 years or less (for the Fast Reactor Recycle and Thermal/Fast Reactor Recycle Alternatives) or to 55,000 years (for the Thermal Reactor Recycle Alternative (Option 1)). Moreover, recycling has the potential to significantly reduce the thermal loading on any geologic repository (in the best case, up to a factor of 235 relative to the No Action Alternative). This could be a substantial reduction in heat load. Finally, the reprocessing of the spent fuel would be designed to meet nonproliferation objectives and would avoid separation of pure plutonium.

The closed fuel cycle offers the potential for near-term deployment with variations to existing separations, fuel and reactor technologies. Commercial spent fuel reprocessing is presently being done in other countries, while the recovered material is recycled in mixed-oxide fuel for existing light water reactors. Consequently, the near-term deployment (by approximately 2020) could allow the recycle of spent nuclear fuel generated in amounts beyond the Yucca Mountain geologic repository statutory capacity, rather than storing it pending development of the additional geologic disposal capacity required if spent fuel were to be directly disposed. Recycling spent nuclear fuel could also delay the need for, and decrease the magnitude of, additional geologic repository capacity compared to direct disposal of spent nuclear fuel. A longer-term strategy could include the use of advanced separations and reactor technologies. The potential to use variations to existing separations technology in the near-term could allow time, where necessary, to complete additional research, development and demonstration on advanced separations and reactor technologies, if pursued. The closed fuel cycle also supports expansion of nuclear energy by making better use of uranium resources.

S.5 INTERNATIONAL INITIATIVES

The Energy Information Administration (EIA) projects that worldwide generation of electricity will nearly double by 2030. The EIA also projects that electricity generated by nuclear power will increase by about 40 percent in that time, as increasing fossil fuel prices, energy security concerns, improved reactor designs and environmental considerations are expected to improve prospects for new nuclear power plants in many countries (EIA 2008b). Accordingly, the U.S., through the GNEP Program, is considering various initiatives to work cooperatively with other nations to expand nuclear power to help meet growing energy demand, develop and deploy advanced nuclear recycling and reactor technologies, establish international frameworks to provide nuclear fuel supplies, and promote the development of nuclear safeguards and of more proliferation-resistant nuclear power reactors.

At this time, DOE has no specific proposals for the international component of the GNEP Program. Rather, as a preliminary step in this PEIS, DOE addresses two potential international initiatives that could affect the global commons and the environment in the U.S.—**Grid-Appropriate Reactors** and **Reliable Fuel Services**.

> **Grid-Appropriate Reactors** are nuclear power reactors designed and sized to achieve high standards of safety and security, and satisfy the power grid requirements of the receiving country.
>
> **Reliable Fuel Services** is an initiative under which nuclear suppliers would provide an assured supply of new nuclear fuel to countries pursuing nuclear power programs, and would assist such countries with management of the resulting spent fuel.

S.5.1 Grid-Appropriate Reactors

Under this initiative, DOE would support the development of grid-appropriate reactors to meet the capabilities and electricity demand needs of developing countries. These reactors would be designed and sized to suit those countries' smaller and less developed power grids. Smaller nuclear power plants (less than 500 megawatts electric) would be well suited for use in these countries as they are more able to meet grid capacities, offer simplified operations with greater margins of safety, require less capital outlay to develop and allow countries to add capacity in smaller increments to match electricity demand.

The successful deployment of these reactors, coupled with reliable fuel services, would provide an attractive energy solution to many countries. Although it is the responsibility of private industry to develop and market commercial nuclear power plants, DOE could support the development of grid-appropriate reactors by assisting U.S. industry efforts to standardize reactor designs and to obtain licensing of these reactors for export to developing countries.

S.5.2 Reliable Fuel Services

Under this initiative, DOE, working with other international nuclear fuel supplier nations, would develop mechanisms to provide an assured supply of fresh nuclear fuel to countries pursuing nuclear power programs. This initiative would build on complementary ongoing programs, including the Reliable Access to Nuclear Fuel program of the International Atomic Energy Agency (an organization within the United Nations) and a National Nuclear Security Administration (a separately organized agency within DOE) program to blend down excess highly enriched uranium to create new (low enriched) fuel to support a reliable fuel supply. In addition, a Reliable Fuel Services Program could help other countries manage the resulting spent nuclear fuel.

The objective of a Reliable Fuel Services initiative is to limit the spread of enrichment and reprocessing by offering countries an alternative to developing such facilities indigenously. Countries using such services would receive the benefit of having reliable access to nuclear fuel services without having to make the significant infrastructure investments required for enrichment and reprocessing.

Under this initiative, spent nuclear fuel could be returned to the country that supplied it or to a third party supplier nation. If the country taking the spent fuel had a closed fuel cycle, it could process that fuel, and the uranium and other usable transuranics could be separated and used to fabricate new fuel for recycle. Alternatively, if the country accepting the spent nuclear fuel had a once-through fuel cycle, it would store the spent fuel pending disposal. The radioactive waste from recycling would be stored or disposed of either by the supplier nation (the nation that provided the fresh fuel), returned to the user nation (the nation that generated the spent fuel), or sent to a third-party nation (a nation that neither supplied the fresh fuel nor generated the spent nuclear fuel).

S.6 ENVIRONMENTAL IMPACTS OF INTERNATIONAL INITIATIVES

The Grid Appropriate Reactor and Reliable Fuel Services initiatives could produce environmental impacts within the U.S. and the global commons. To determine these impacts, DOE focused on the transportation impacts based on a scenario involving 1 gigawatt electric of foreign light water reactor production. This reactor production would require sufficient fresh fuel for initial start-up and steady-state operations.[18] Under this scenario, fresh fuel would be manufactured in the U.S. or a foreign partner nation, and the fresh fuel assemblies would be shipped to the user nation for use in the reactor. Following use, the spent fuel resulting from operation would be returned to the U.S. or a foreign partner nation.

For open fuel cycle alternatives, the spent fuel would be transported to and disposed of in a geologic repository. For closed fuel cycle alternatives, the spent fuel would be recycled in a nuclear fuel recycling center. The useful constituents would be fabricated into fuel assemblies to provide fuel for U.S. or partner nation reactors (not for reuse in a foreign user nation's reactor in this scenario). Any waste materials from recycling would be stabilized, appropriately packaged for shipment and potentially could be disposed of or returned to the user nation.

Based on the analysis of impacts associated with handling, shipping, and receiving all radiological materials associated with international initiatives, DOE estimates that the fuel cycle alternatives would result in a total dose to the public of less than 100 person-rem; resulting in much less than 1 latent cancer fatality, for activities to support every gigawatt of foreign reactor production.

S.7 CONCLUSIONS

S.7.1 Major Conclusions

1. Geologic Disposal Capacity:

   - The closed fuel cycle alternatives offer the greatest opportunity to reduce the impacts associated with disposal of future spent fuel (e.g., by reducing the volume, thermal output and/or radiotoxicity of waste requiring geologic disposal).

   - All domestic programmatic alternatives would require the development of additional geologic repository capacity, in excess of the statutory capacity limit for the proposed Yucca Mountain repository, for disposal of spent fuel and/or high-level radioactive waste.

   - Compared to the No Action Alternative, the Fast Reactor Recycle Alternative and the Thermal/Fast Reactor Recycle Alternative have the potential for the largest reduction in the volume, radiotoxicity, and thermal output with respect to material that would require disposal in a geologic repository.

[18] DOE analyzed the steady-state impacts associated with annual operations; the initial start-up of a foreign reactor would require approximately 3-4 times as much start-up fuel as were analyzed for steady-state annual operations.

- The Thermal Reactor Recycle Alternative (Option 1) also provides the potential for a relative reduction in volume, radiotoxicity and thermal output of material requiring geologic disposal, though not as great of a reduction as that provided under the Fast Reactor Recycle and Thermal/Fast Reactor Recycle Alternatives.

- The open fuel cycle alternatives (Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative and Thorium Alternative) and the Thermal Reactor Recycle Alternative (Option 2) provide the least potential net repository capacity benefit when compared to the No Action Alternative.

  - The All-Heavy Water Reactor Option would result in slightly higher radiotoxicity, higher spent fuel volume and higher thermal output of spent fuel requiring geologic disposal than the No Action Alternative.
  - The All-High Temperature Gas-Cooled Reactor Option would result in lower radiotoxicity and thermal load, but also would result in a larger volume of spent fuel requiring geologic disposal than the No Action Alternative.
  - The Thorium Alternative would result in a lower spent fuel volume and thermal output, but would result in a higher radiotoxicity than the No Action Alternative.
  - The Thermal Reactor Recycle Alternative (Option 2) would result in a slightly lower spent fuel volume, lower thermal output and the potential for some reduction in radiotoxicity.
  - For the HWR and HTGR open fuel cycle alternatives and the Thermal Reactor Recycle Alternative (Option 2), it is not clear that any reduction in future geologic capacity would be realized when compared to the No Action Alternative.

2. Implementability and Transition:

- Research and Development. The timing of implementation of alternatives would be influenced by the R&D needs as well as other factors.

  - Fuels Fabrication and Fuel Performance: Most of the alternatives have candidate processes for fabrication of fuel; however, all but the No Action Alternative and the All-Heavy Water Reactor Option would require additional R&D to apply these technologies. The time frame to complete the necessary R&D would be similar among the alternatives, an estimated 5 to 10 years.

  - Spent Nuclear Fuel Reprocessing: For closed fuel cycle alternatives, there are many subsidiary issues associated with each new technology that would require R&D, especially with final treatment and consolidation of the wastes, and with ensuring the availability of technologies that are capable of maintaining any releases of radioactive materials from the processing plant to within allowable limits as specified in licensing.

- Transition: Transition would be the least complicated for the alternatives that require new fuels with current reactor types. This includes the Thorium Alternative and the

Thermal Reactor Recycle Alternative (Option 1). Alternatives that would transition from the current light water reactors to a system involving more than one reactor type in a balanced system (this includes the Fast Reactor Recycle Alternative, the Thermal/Fast Reactor Recycle Alternative and the Thermal Reactor Recycle Alternative [Options 2 and 3]) could have the most complex transition. However, under the Thermal/Fast Reactor Recycle Alternative, the potential exists to begin implementation using existing reactor and variations to existing separations technologies and later transition to advanced reactor and separations technologies. The start of transition for the Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and Thermal Reactor Recycle Alternative (Options 2 and 3) would involve both new reactors and nuclear fuels, and the new fuels could require separations to provide a sustained feedstock.

- Facility and Resource Requirements: All alternatives would require uranium enrichment and fuel fabrication facilities. The closed fuel cycle alternatives (Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and the Thermal Reactor Recycle Alternative [all options]) would require light water reactor spent fuel separation facilities/fuel fabrication facilities. Facilities to produce heavy water also would be required to implement the Thermal Reactor Recycle Alternative (Option 2) and the All-Heavy Water Reactor Option. All fuel cycle alternatives would require significant quantities of natural uranium feed. The open fuel cycle alternatives (No Action Alternative, Thorium Alternative and Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative) would require the highest quantities of natural uranium feed. The Thermal Reactor Recycle Alternative (Option 3) and the All-High Temperature Gas-Cooled Reactor Option could also require construction of a facility to provide the required amount of reactor-grade graphite.

3. Environmental Impacts:

- Human Health: Radiation exposures to the public from reactors under any alternative would be very low and well within regulatory limits. Alternatives with recycling would result in a greater dose to the public and workers than the open fuel cycle alternatives; however, those doses would also be within established regulatory limits.

- Transportation: The All-High Temperature Gas-Cooled Reactor Option would have the highest transportation impacts for truck transport. The Fast Reactor Recycle Alternative, Thermal/Fast Reactor Recycle Alternative and the Thermal Recycle Alternative (Option 1) would have the highest transportation impacts for the combination truck and rail transport.

- Radioactive Waste: The closed fuel cycle alternatives would require less geologic disposal capacity for high-level radioactive waste volumes compared to the volumes of spent fuel from open fuel cycle alternatives. However, the closed fuel cycle alternatives require significantly more disposal capacity for low-level radioactive waste and Greater-than-Class-C low-level radioactive waste than is required under the open fuel cycle alternatives.

- Facility Accidents: Each of the domestic programmatic alternatives could impact public and worker health in the event of an accident. For all alternatives considered, the annual risk of a latent cancer fatality from an accident would be less than one.

- Other Resource Areas: For other resource areas, the differences between alternatives are not significant enough on a programmatic scale to provide a discriminator between alternatives. This includes required uranium enrichment facilities, Land Resources, Visual Resources, Air Resources, Water Resources, and Socioeconomic Resources.

4. Other Benefits:

   - Nuclear reactors emit no greenhouse gases
   - Recycle of spent fuel makes better use of uranium natural resources

S.7.2 Areas of Controversy

During the scoping process, concerns were raised relative to nuclear power in general and the alternatives specifically. DOE believes that several of these areas remain of concern and reflect differing points of view or irreducible uncertainties.

1. Nuclear power is and will likely remain controversial. Although nuclear power is perhaps becoming less controversial because of its expanded use throughout the world and the environmental benefits it offers for addressing greenhouse gas emissions, there continue to be concerns about safe disposition of spent fuel. DOE is making significant progress in developing a geologic repository at Yucca Mountain for the disposal of high-level radioactive waste and spent fuel; however, there is currently no licensed geologic repository for the disposal of these materials, and the siting and development of additional future repository capacity will likely remain controversial.

2. Recycling of spent fuel is and will likely remain controversial. In the past, the processing of spent fuel and other materials associated with the defense nuclear weapons complex has produced significant environmental impacts, including the creation of millions of gallons of liquid high-level radioactive waste at several DOE sites requiring many billions of dollars to prepare that waste for geological disposal. These activities have resulted in radioactive and hazardous material contamination of land and groundwater at these sites. Additionally, recycling is perceived by some as creating a high risk of nuclear proliferation.

3. Transportation of radiological materials, particularly spent nuclear fuel and high-level radioactive waste, is and likely will remain controversial.

4. Sodium-cooled fast reactors, high temperature gas-cooled reactors and thorium-fueled reactors have not yet proven to be economically competitive with light water reactors.

5. The safety and environmental record of commercial nuclear power generating facilities is well established; nevertheless, the safety of nuclear power facilities is and will likely remain controversial.

S.7.3 Issues to be Resolved

The implementation of any programmatic alternative would require these primary issues to be resolved:

1. Utilities, public utility regulatory bodies, and the financial markets would need to be convinced that an alternative would provide an adequate return on capital. This would require that the alternative be demonstrated to be cost-effective and economical compared to other means of generating electricity.

2. Any new commercial nuclear facility (spent fuel recycling center, enrichment facility, fuel fabrication facility and reactor) would be subject to permitting or licensing decisions by a number of different government agencies. Changes to the regulatory framework may be needed to enable the licensing of these nuclear facilities, some of which would be first-of-a-kind facilities.

3. For the programmatic alternatives that involve recycle of spent fuel, a regulatory system that provides for appropriate protection to the public health, safety and the environment may need to be modified or developed to address potential new waste categories. An example of this need would be to determine the appropriate disposition path for cesium and strontium wastes from a spent fuel recycling center if segregated as a separate waste stream.

4. The nature and extent of Government involvement or encouragement in the implementation of any alternative, including providing financial and other incentives, continuing R&D and conducting demonstrations of technologies would need to be determined.

S.8 REFERENCES

10 CFR 61.55 — U.S. Nuclear Regulatory Commission (NRC), "Waste Classification," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised January 1, 2008.

10 CFR 72.3 — NRC, "Definitions," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised January 1, 2008.

40 CFR 1501.7 — Council on Environmental Quality (CEQ), "Scoping," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised July 1, 2007.

40 CFR 1502 — CEQ, "Environmental Impact Statement," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised July 1, 2007.

40 CFR 1508.7 — CEQ, "Cumulative Impacts," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised July 1, 2007.

71 FR 14505 — U.S. Department of Energy (DOE), "Advance Notice of Intent To Prepare an Environmental Impact Statement for the Global Nuclear Energy Partnership Technology Demonstration Program," Office of the Federal Register, National Archives and Records Administration, Washington, DC, March 22, 2006.

72 FR 331 — DOE, "Notice of Intent To Prepare a Programmatic Environmental Impact Statement for the Global Nuclear Energy Partnership," Office of the Federal Register, National Archives and Records Administration, Washington, DC, January 4, 2007.

72 FR 40135 — DOE, "Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste," Office of the Federal Register, National Archives and Records Administration, Washington, DC, July 23, 2007.

42 U.S.C. 10101 et seq. — "Nuclear Waste Policy Act of 1982," NWPA, *United States Code*, Washington, DC, January 7, 1983.

DOE 1999d DOE, "Surplus Plutonium Disposition Final Environmental Impact Statement," DOE/EIS-0283, Office of Fissile Materials Disposition, U.S. Department of Energy, Washington, DC, November 1999.

DOE 2002i DOE, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," DOE/EIS-0250, U.S. Department of Energy, Washington, DC, February 1, 2002.

DOE 2006n DOE, "Financial Assistance Funding Opportunity Announcement Global Nuclear Energy Partnership (GNEP) Siting Studies," Funding Opportunity Number: DE-PS07-06ID14760, U.S. Department of Energy, Washington, DC, 2006.

DOE 2006p DOE, "Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports," DOE-STD-3009-94, U.S. Department of Energy, Washington, DC, July 1994, Change Notice No.1, January, 2002, Change Notice No.2, April 2002, Change Notice No.3, March 2006.

DOE 2006t DOE, "The U.S. Generation IV Fast Reactor Strategy," DOE/NE-0130, Office of Nuclear Energy, U.S. Department of Energy, Washington, DC, December 2006.

DOE 2008f DOE, "Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," DOE/EIS-0250F-S1, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, Washington, DC, June 2008.

EIA 2007a Energy Information Administration (EIA), "AEO2008, Annual Energy Outlook 2008 (Early Release)," DOE/EIA-0383, Energy Information Administration, U.S. Department of Energy, Washington, DC, December 2007. Accessed at http://www.eia.doe.gov/oiaf/aeo/pdf/earlyrelease.pdf on January 22, 2008.

EIA 2008a EIA, "Annual Energy Outlook 2008 With Projections to 2030," DOE/EIA-0383 (2008), Energy Information Administration, U.S. Department of Energy, Washington, DC, June 2008. Accessed at http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf on July 3, 2008.

EIA 2008b	EIA, "International Energy Outlook 2008: Highlights," DOE/EIA-0484(2008), Energy Information Administration, U.S. Department of Energy, Washington, DC, June 2008. Accessed at http://www.eia.doe.gov/oiaf/ieo/world.html on July 3, 2008.
Goldner and Versluis 2006	Goldner, F. and R. Versluis, "Transmutation Capabilities of GEN-IV Reactors," Global Nuclear Energy Partnership Program, U.S. Department of Energy, Washington, DC, September 28, 2006.
Health Canada 2008	Health Canada, "2007 Report on Occupational Radiation Exposures in Canada," Minister of Health, Canada, 2008.
IAEA 2002b	International Atomic Energy Agency (IAEA), "Thorium Fuel Utilization: Options and Trends," IAEA-TECDOC-1319, Proceedings of Three IAEA Meetings held in Vienna in 1997, 1998, and 1999, November 1, 2002.
MIMS 2008	Manifest Information Management System (MIMS), "Volume and Activity Summary," U.S. Department of Energy, Washington, DC, 2008. Accessed at http://mims.apps.em.doe.gov/mims.asp# on August 15, 2008.
NRC 1977b	NRC, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," NUREG-0170, Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, DC, December 1977.
NRC 1990	NRC, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, U.S. Nuclear Regulatory Commission, Washington, DC, December 1990. Accessed at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1150/ on September 08, 2008.
NRC 2007g	NRC, "Year 2005 Low-Level Waste Disposal Statistics," U.S. Nuclear Regulatory Commission, Washington, DC, March 21, 2007.
NRC 2007l	NRC, "Occupational Radiation Exposure at Nuclear Power Reactors and Other Facilities 2006," Thirty-Ninth Annual Report, NUREG-0713, U.S. Nuclear Regulatory Commission, Washington, DC, December 2007.
PMC 1982	PMC, "Clinch River Breeder Reactor Project—Preliminary Safety Analysis Report," Volume 1-Volume 14, Project Management Corporation, May 1982.

Todosow 2007b	Email from Michael Todosow, Brookhaven National Laboratory to Jay Rose, Tetra Tech "PEIS Thorium," October 17, 2007.
Wigeland 2008a	Wigeland, R.A., "Performance Summary of Advanced Nuclear Fuel Cycles," GNEP-TIO-AI-AI-RT-2008-000268, Revision 1, Idaho National Laboratory, Nuclear Science & Technology, June 10, 2008.
Wigeland 2008c	Wigeland, R.A., "Cs/Sr Waste Volume Estimates," Addendum to the "Performance Summary of Advanced Nuclear Fuel Cycles" GNEP-TIO-AI-AI-RT-2008-000268, Revision 1, Idaho National Laboratory, Nuclear Science & Technology, August 18, 2008.
Yang and Park 2006	Yang, M.S., and J.H. Park, "Korean Assessment of the Proliferation Resistance on the Whole Fuel Cycle of DUPIC," Korean Atomic Energy Research Institute, 2006.