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FMDP Reactor Alternative Summary Report Vol. 1—Existing LWR Alternative

Reactor Alternative Team
Fissile Materials Disposition Program

MANAGED AND OPERATED BY
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Acronyms and Abbreviations

ABB-CE	Asea Brown Boveri–Combustion Engineering
ABWR	advanced boiling water reactor
AE	architect-engineer
AEA	Atomic Energy Act of 1954
AECL	Atomic Energy of Canada, Limited
AFI	allowance for indeterminates
AFUDC	allowance for funds used during construction
ALARA	as low as reasonably achievable
ANL	Argonne National Laboratory
ARIES	Advanced Recovery and Integrated Extraction System
ASLB	Atomic Safety Licensing Board
B&W	Babcock & Wilcox
BAPL	Bettis Atomic Power Laboratory
BNFL	British Nuclear Fuels, Limited
BNL	Brookhaven National Laboratory
BOP	balance-of-plant
BWR	boiling-water reactor
CANDU	Canadian deuterium-uranium reactor
Ci	curie
CFR	Code of Federal Regulations
CRNL	Chalk River Nuclear Laboratory
CRWMS	Civilian Radioactive Waste Management System
C/S	containment and surveillance
D&D	decontamination and decommissioning
DLCC	discounted life cycle cost
DNA	Defense Nuclear Agency
DNFSB	Defense Nuclear Facilities Safety Board
DoD	Department of Defense
DOE	Department of Energy
DOE/MD	Department of Energy Office of Fissile Materials Disposition
DOT	Department of Transportation
DP	Defense Programs
DSC	dry shielded canister
DUI	direct-use irradiated
DUU	direct-use unirradiated
EA	environmental assessment
EC	estimated cost
EFPD	effective full-power days
EIA	Energy Information Agency
EIS	Environmental Impact Statement
ELWR	evolutionary light-water reactor
EPA	Environmental Protection Agency
EPACT	Energy Policy Act of 1992

ER	environmental report
ES&H	environment, safety, & health
EURATOM	European Community's Safeguarding Agency
FFTF	Fast Flux Test Facility
FILO	first in, last out
FMDP	Fissile Materials Disposition Program
FMEF	Fuel and Material Examination Facility
FMLE	full MOX load equivalent
FSU	Former Soviet Union
FTE	full-time equivalent (manpower measure)
G&A	general and administrative
GA	General Atomic
GDP	gaseous diffusion plant
GE	General Electric
GJPO	Grand Junction Project Office
GoCo	government-owned contractor-operated
HEU	highly enriched uranium
HLW	high-level waste (radioactive)
HM	heavy metal
HSM	horizontal storage module
HWR	heavy-water reactor
HYDOX	hydride/dehydride/oxidation
IAEA	International Atomic Energy Agency
ICPP	Idaho Chemical Processing Plant
IFBA	integral fuel burnable absorber
INEL	Idaho National Engineering Laboratory
ITAAC	Inspections, Tests, and Analyses of Acceptance Criteria
ITRI	Inhalation Toxicology Research Institute
IWG	Interagency Working Group
KAPL	Knolls Atomic Power Laboratory
KD	key decision
LA	license amendment, limited area
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkley Laboratory
LCC	life cycle cost
LEHR	Laboratory for Energy-Related Health Research
LEU	low-enriched uranium
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste (radioactive)
LTA	lead-test assembly
LUA	lead use assembly
LWR	light-water reactor
M&O	management and operating contractor
MAA	materials access area
MBA	material balance area
MC&A	materials control and accounting

MOU	Memorandum of Understanding
MOX	mixed oxide (plutonium plus uranium)
MT	metric ton
MTHM	metric tons heavy metal
MW	mixed waste (radioactive)
MWd	megawatt-days
MW(e)	megawatts electric power
MW(t)	megawatts thermal output
NAS	National Academy of Sciences
NBL	New Brunswick Laboratory
NEPA	National Environmental Policy Act of 1969
NDA	nondestructive assay
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
O&M	operations and maintenance
OCRWM	Office of Civilian Radioactive Waste Management
OL	operating license
OPC	operating-funded project cost
ORISE	Oak Ridge Institute of Science and Education
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PA	protected area
PCV	primary containment vessel
PDD-13	Presidential Decision Directive-13, "U.S. Nonproliferation and Export Control Policy," September 27, 1993
PDR	plutonium disposition reactor
PEIS	Programmatic Environmental Impact Statement
PGDP	Paducah Gaseous Diffusion Plant
PHB	Putnam, Hayes, and Bartlett
PIDAS	perimeter intrusion detection and assessment system
PIE	postirradiation examination
PILT	payments-in-lieu of taxes
PSF/NSR	plutonium storage facility/new special recovery
Pu	plutonium
PuO_2	plutonium oxide
PuP	plutonium processing
PWR	pressurized-water reactor
QA	quality assurance
RASR	Reactor Alternative Summary Report
RD&D	research, development, and demonstration
R&D	research and development or research and engineering development
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RFP	request for proposal
RxAT	Reactor Alternative Team
ROD	Record of Decision

S&S	safeguards and security
SAR	safety analysis report
SBWR	simplified boiling-water reactor
SER	safety evaluation report
SFS	Spent Fuel Standard
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SNL-CA	Sandia National Laboratories, California Site
SNM	special nuclear material
SRS	Savannah River Site
SST	safe, secure trailer
START	Strategic Arms Reduction Treaty
SWU	separative work unit
TDLCC	total discounted life cycle cost
TEC	total estimated cost
TID	tamper-indicating device
TLCC	total life cycle cost
TPC	total project cost
TRU	transuranic waste (radioactive)
TSD	Transportation Safeguards Division (DOE)
TSR	Technical Summary Report
U	uranium
UO_2	uranium oxide
VA	vital area
WIPP	Waste Isolation Pilot Plant (Carlsbad, NM)
WSRC	Westinghouse Savannah River Company

1. Introduction

Significant quantities of weapons-usable fissile materials [primarily plutonium and highly enriched uranium (HEU)] are becoming surplus to national defense needs in both the United States and Russia. These stocks of fissile materials pose significant dangers to national and international security. The dangers exist not only in the potential proliferation of nuclear weapons but also in the potential for environmental, safety, and health (ES&H) consequences if surplus fissile materials are not properly managed.

1.1 Weapons-Usable Plutonium Inventories—A Cold War Legacy

The first and second Strategic Arms Reductions Treaties (START I and START II) call for deep reductions in the strategic nuclear forces of both the United States and the former Soviet Union. In addition, in the aftermath of the Cold War, both the United States and Russia have initiated unilateral steps to increase the pace of strategic disarmament. Under START and subsequent unilateral initiatives, some 10,000 to 20,000 warheads in the United States (and a similar or greater number in the former Soviet Union) could possibly be declared "surplus" to national security needs. Thus, significant quantities of weapons-usable fissile materials have or will become surplus to national defense needs in both the United States and Russia.

1.2 Recent Developments

In September 1993, President Clinton issued the U.S. Nonproliferation and Export Control Policy,[1] which commits the United States to undertake a comprehensive management approach to the growing accumulation of fissile materials from dismantled nuclear weapons. This policy directs that the United States will do the following:

- *Seek to eliminate, where possible, accumulation of stockpiles of highly enriched uranium or plutonium, and to ensure that where these materials already exist they are subject to the highest standards of safety, security, and international accountability.*
- *Initiate a comprehensive review of long-term options for plutonium disposition, taking into account technical, nonproliferation, environmental, budgetary and economic considerations. Russia and other nations with relevant interests and experience will be invited to participate in the study.*

Further, in January 1994, President Clinton and Russia's President Yeltsin issued the *Joint Statement Between the United States and Russia on Nonproliferation of Weapons of Mass Destruction and Means of Their Delivery*. In accordance with these policies, the focus of the U.S. nonproliferation efforts is fivefold: to secure nuclear materials in the former Soviet Union; to ensure safe, secure, long-term storage and disposition of surplus fissile materials; to establish transparent and irreversible nuclear reductions; to strengthen the nuclear nonproliferation regime; and to control nuclear exports.

To demonstrate the U.S. commitment to the five objectives articulated in the joint statement, President Clinton announced on March 1, 1995, that 200 metric tons (MT) of U.S. fissile materials (~38.2 MT of which is weapons-grade plutonium) had been declared surplus to U.S. nuclear defense needs.[2] In addition, it is anticipated that several metric tons of reactor-grade material containing weapons-usable plutonium will be declared surplus in the future. Thus, it appears that ~50 MT of weapons-usable plutonium will become surplus to U.S. defense needs. Russia has designated ~50 MT of weapons-usable plutonium and 400 MT of HEU to be surplus to its national defense needs.

1.3 The Danger Posed by Surplus Plutonium Inventories

In its 1994 study, *Management and Disposition of Excess Weapons Plutonium*,[3] the National Academy of Sciences (NAS) stated, *"The existence of this surplus material constitutes a clear and present danger to national and international security."* In many respects, the nuclear threat posed by this material is now more diffuse, harder to manage, and more dangerous than the nuclear tensions of the Cold War era. The international community is concerned about the adequacy of safeguards and security (S&S) of this material, the dangers associated with the potential

proliferation of nuclear weapons, and the potential for environmental, safety, and health (ES&H) consequences if surplus fissile materials are not properly managed. In a joint communiqué from the Moscow Nuclear Safety Summit,[4] the leaders of the seven largest industrial countries and the Russian Federation endorsed the need to render surplus plutonium in Russia and the United States as proliferation-resistant as possible.

In June 1994, the Department of Energy (DOE) issued a Notice of Intent to prepare a "Programmatic Environmental Impact Statement (PEIS) for Long-Term Storage and Disposition of Weapons-Usable Fissile Materials" and to issue a Record of Decision (ROD) regarding long-term storage and disposition of weapons-usable fissile materials. The primary goal of disposition is to render weapons-usable fissile materials inaccessible and unattractive for weapons use while protecting human health and the environment. In its 1994 report, the NAS recommended that plutonium disposition strategies endeavor to attain the "Spent Fuel Standard" (SFS). The NAS defined the SFS as follows:

> *We believe that options for the long-term disposition of weapons plutonium should seek to meet a "spent fuel standard"—that is, to make this plutonium roughly as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in spent fuel from commercial reactors.*[3]

"...make the plutonium as unattractive and inaccessible for retrieval and weapons use as the residual plutonium in the spent fuel from commercial reactors."

DOE has subsequently revised the SFS definition:

> *...make the plutonium as unattractive and inaccessible for retrieval and weapons use as the residual plutonium in the spent fuel from commercial reactors.*

The enhanced SFS makes explicit the concepts of material attractiveness and potential use in weapons, which were implicit in the NAS definition.

The SFS does not imply that conversion of the plutonium to spent nuclear fuel (SNF) is the *only* way to achieve the SFS, but rather that approaches should effect an equivalent level of proliferation resistance. Thus, achieving the SFS provides increased proliferation resistance by transforming surplus fissile materials into a less accessible form; it leads to decreased reliance on institutional barriers to protect the material from theft or diversion.

1.4 DOE's Role in Plutonium Disposition

Following President Clinton's September 1993 nonproliferation policy announcement, an Interagency Working Group (IWG) was established to conduct a comprehensive review of the options for disposition of surplus plutonium from nuclear weapons activities of the United States and the former Soviet Union. The IWG is cochaired by the White House Office of Science and Technology Policy and the National Security Council. In response to the President's nonproliferation policy, Secretary O'Leary created a department-wide project for control and disposition of surplus fissile materials on January 24, 1994. Later that year, this project became the Office of Fissile Materials Disposition (DOE/MD). The DOE has a lead role within the IWG for evaluating technical options and developing analyses of economic, schedule, environmental, and other aspects of potential disposition options.

Figure 1.1 is a simplified illustration of the overall fissile materials disposition decision process. The purpose of the process is to provide an orderly analysis of potential alternatives for plutonium disposition as input to the ROD. The detailed evaluation consists of a thorough assessment of the reasonable alternatives to be presented in the PEIS, along with a parallel, two-step process that includes technical, economic, and nonproliferation analyses. This evaluation will determine preferred alternatives and ultimately support the ROD.

The screening process, the first step in implementing the President's September 1993 Nonproliferation Policy, was completed in March 1995 with the publication of DOE's Summary Report of the Screening Process.[5] That report summarized the results of a study conducted to identify a spectrum of reasonable alternatives for long-term storage and disposition of surplus weapons-usable materials (plutonium, HEU, and ^{233}U). Thirty-five alternatives

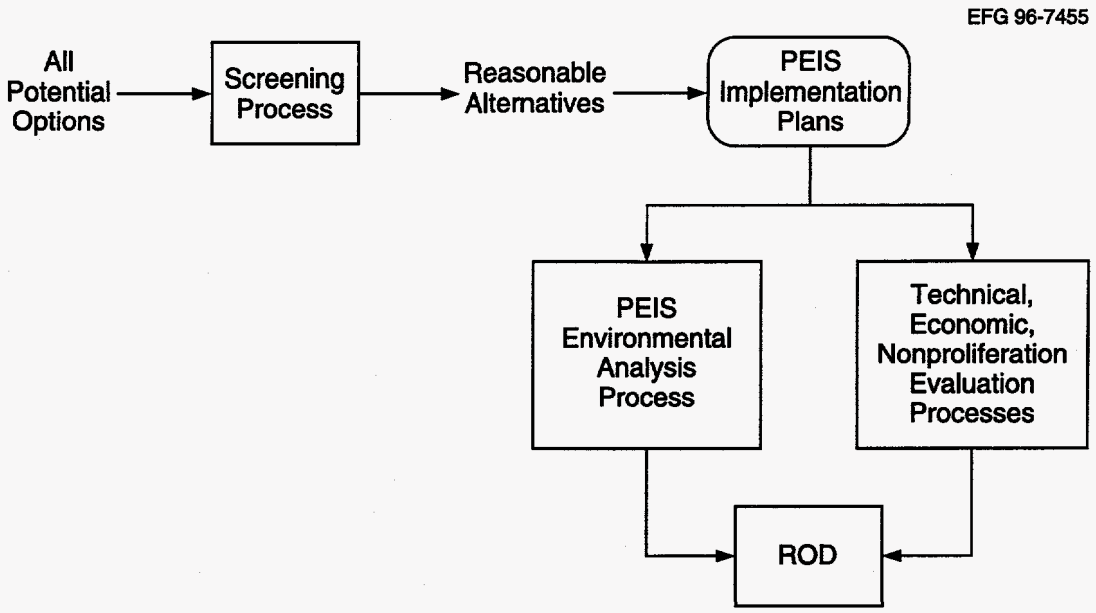

Figure 1.1. Fissile Materials Disposition Program ROD process

for plutonium disposition were considered in the screening analysis. Sixteen of these alternatives involved the use of uranium/plutonium mixed-oxide (MOX) fuel in nuclear reactors to convert the plutonium to a form similar to that contained in commercial spent nuclear reactor fuel.

Five of the reactor-based plutonium disposition alternatives, two borehole alternatives, and four immobilization alternatives were ultimately selected as reasonable plutonium disposition alternatives for further evaluation in the PEIS and detailed technical, economic, and nonproliferation evaluations. The five reactor-based plutonium disposition alternatives are existing light-water reactors (LWRs), [both pressurized water reactors (PWRs) or boiling water reactors (BWRs)]; the Canadian deuterium-uranium (CANDU) heavy-water reactors (HWRs); partially complete LWRs; evolutionary LWRs (ELWRs); and EuroMOX (an alternative in which PuO_2 is transported to Europe, fabricated into MOX fuel in European facilities, irradiated in commercial European reactors, and emplaced in European high level waste (HLW) repositories). The EuroMOX alternative was subsequently dropped from consideration (see Appendix A).

A reactor-based plutonium disposition alternative is defined as the entire sequence of processes and facilities necessary for conversion of stable, stored, weapons-usable plutonium forms into MOX fuel, irradiation of the plutonium bearing MOX fuel in commercial nuclear reactors, and the geologic emplacement of the spent MOX fuel from the reactors (Fig. 1.2). The fabrication and utilization of MOX fuel are well-established, mature commercial technologies. Three commercial MOX fuel fabricators currently exist in Europe, where more than 40 commercial power reactors are licensed to use MOX fuel. Reactor-based disposition of plutonium requires no new or novel technologies or processes and involves no major technical risks. Unlike other plutonium disposition approaches, the reactor-based plutonium disposition alternatives extract and utilize the electric energy generation potential of plutonium by fueling the operation of two or more commercial nuclear power stations.

1.5 Purpose of This Report

Following the screening process, DOE/MD, using its national laboratories, initiated a more detailed analysis of the ten plutonium disposition alternatives that survived the screening process. Three "Alternative Teams" chartered by DOE and comprised of technical experts from across the DOE national laboratory complex conducted these analyses. One team was chartered for each of the major disposition classes (borehole, immobilization, and reactors).

During the last year and a half, the Fissile Materials Disposition Program (FMDP) Reactor Alternative

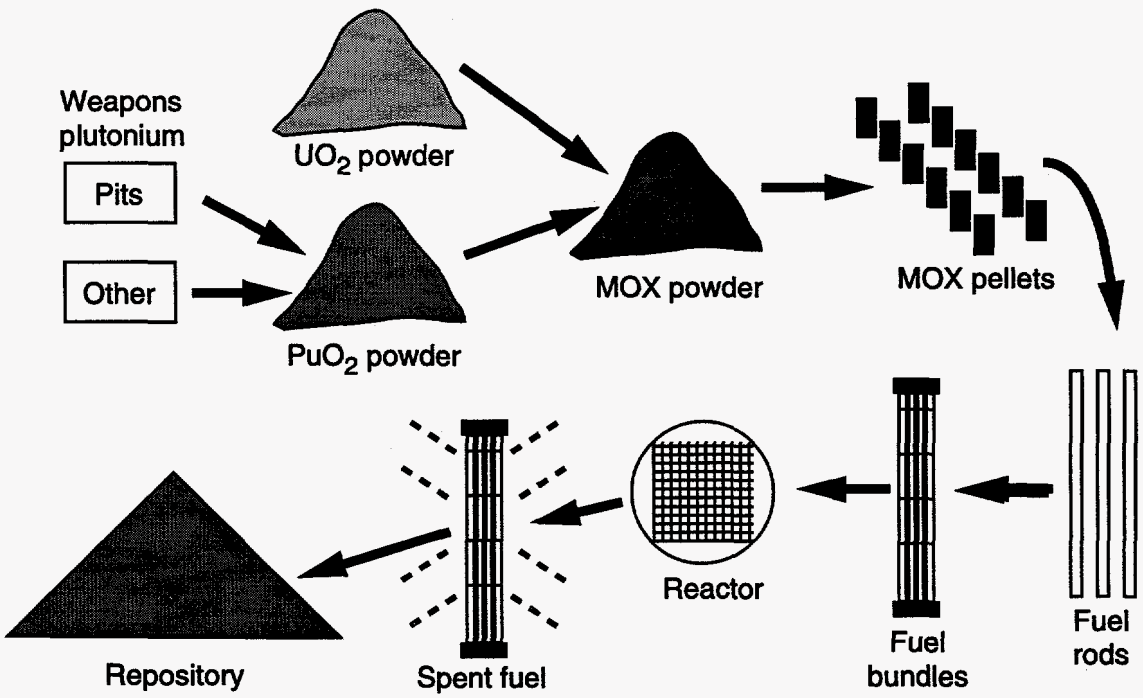

Figure 1.2. Generic reactor alternative

Team (RxAT) has conducted extensive analyses of the cost, schedule, technical maturity, S&S, and other characteristics of reactor-based plutonium disposition. This document (Volume 1 of the four-volume report) summarizes the results of these analyses for the existing LWR plutonium disposition alternative. The results of the RxAT's analyses of the CANDU, partially complete LWR, and evolutionary LWR alternatives are documented in Volumes 2–4 of this report. This multivolume Reactor Alternative Summary Report has been summarized in DOE's recently published FMDP Technical Summary Report (TSR).[6]

Chapter 2 presents the results of all analyses conducted to date for the existing LWR alternative base case. Schedule, cost, S&S, technical viability, transportation, and "other benefits" derived from using this option are discussed for the plutonium processing (PuP) facility, MOX fuel fabrication facility, reactor facility, and repository. Licensing, construction, operations, and decontamination and decommissioning (D&D) are described for each facility.

Chapters 3 through 6 present analyses of variants to the base case LWR alternative. In each chapter, schedule, cost, S&S, technical viability, transportation, and "other benefits" derived from using the option are discussed for the facilities involved. Licensing, construction, operations, and D&D are described for each facility. To minimize repetition, only results that differ from the base case alternative are presented.

Chapter 3 presents an analysis for the existing LWR option in which all facilities are the same as in Chap. 2, except that the MOX fuel fabrication facility is privately owned.

Chapter 4 provides an analysis for an existing LWR option that uses four BWRs and collocated PuP and MOX facilities.

Chapter 5 presents an analysis of the existing LWR option that uses the same plutonium processing and reactor facilities described in Chap. 2, but that starts at an earlier date by initially using PuO_2 from U.S. prototype facilities to feed MOX fuel fabrication facilities in Europe. This variant subsequently shifts to MOX fuel fabricated in the United States.

Chapter 6 presents an analysis of a hybrid option in which 32.5 MT of "clean" surplus weapons-grade plutonium is used as a feed for MOX fuel fabrication and irradiation in an LWR reactor, with the remaining surplus plutonium disposed of by other means (vitrification or deep borehole technology).

Chapter 7 provides a summary discussion of the entire existing LWR alternative. Schedule, cost, S&S, technical viability, transportation, and "other benefits" derived from using this reactor disposition alternative are presented.

Appendixes are provided at the end of the volume to provide additional background and supporting information on the existing LWR alternative.

Appendix A provides summary descriptions for all the reactor alternatives and variants. Appendix B presents the approach to developing the schedule information. Appendix C presents the approach to developing the cost information. Appendix D presents the approach for developing the S&S information. Appendix E presents the quantitative technical viability assessment. Appendix F provides a description of the feed materials. Appendix G provides transportation and packaging information. Appendix H describes the differences between the costs and schedules in the TSR[6] and the costs and schedules in Chapters 2–7 of this report. (The only significant difference is the inclusion of business-negotiable cost items in this report, which is simply the incentive fee to be paid to the utility for use of their reactors.) A glossary is provided in Appendix I.

1.6 References

1. Presidential Decision Directive-13, "U.S. Nonproliferation and Export Control Policy," September 27, 1993.
2. DOE Openness Initiative, February 6, 1996.
3. National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, 1994.
4. Joint Declaration from Moscow Nuclear Safety Summit, April 20, 1996.
5. DOE MD-002, *Summary Report of the Screening Process*, March 29, 1995.
6. DOE, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, July 17, 1996.

2. Existing LWR Alternative: Base-Case Variant

2.1 Introduction

The existing LWR alternative base case is a specific form of the generic reactor alternative (Fig. 1.2) in which five existing LWRs are employed to irradiate the MOX fuel.

At present, 110 licensed commercial nuclear power plants are operating in the United States. A number of LWR sites exist that are capable of completing the reactor portion of the plutonium disposition mission. These sites include nuclear steam supply systems furnished by Babcock and Wilcox (B&W), Westinghouse, General Electric (GE), and Asea Brown Boveri-Combustion Engineering (ABB-CE). Figure 2.1 summarizes the projected U.S. commercial nuclear power reactor operating license expiration schedule based on an assumed 40-year license duration.

For the purpose of the analysis presented in this chapter, five existing, privately owned PWRs are employed as surrogates for all large domestic LWRs. The mission is complete for this alternative after the first irradiation cycle of the last core load containing MOX fuel assemblies. Table 2.1 lists the facilities that are included in this alternative.

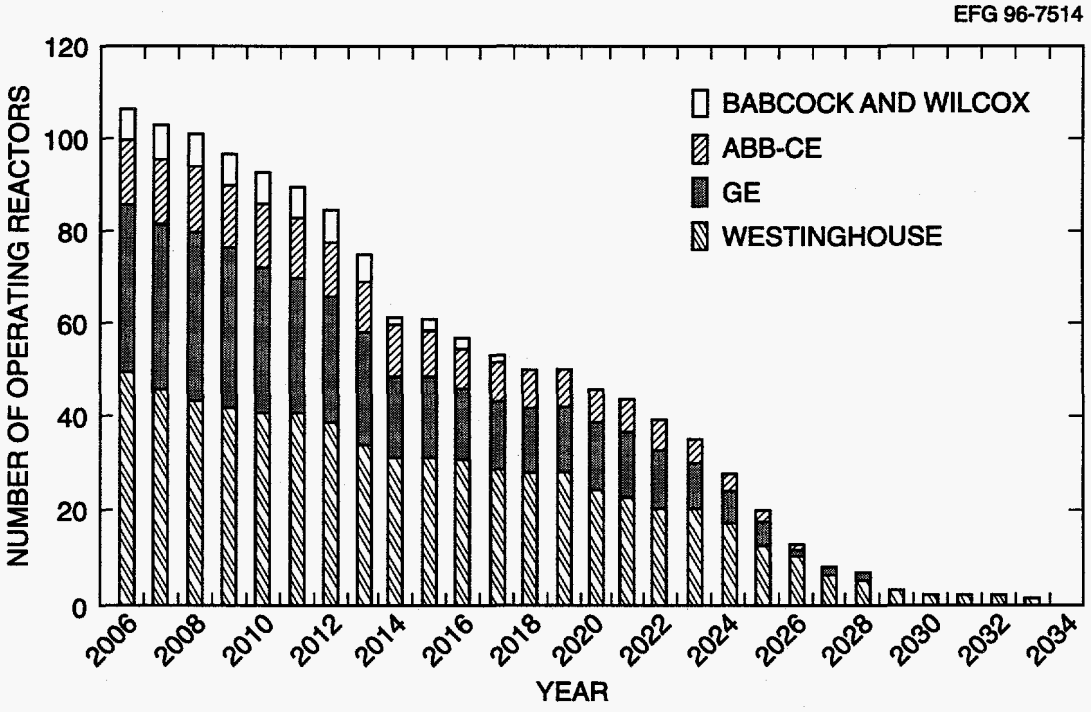

Figure 2.1. U.S. commercial reactor license expiration schedule

Table 2.1. Existing LWR alternative base-case facilities

Reactor type	Number	Ownership of reactor	Ownership of MOX fuel fabrication facility	Collocation of PuP and MOX fuel fabrication facility
Existing light water reactor	5	Private	Federal	No

Although in this base-case alternative a Westinghouse reactor was chosen as the surrogate reactor for all existing LWRs, it is *strongly* emphasized that this selection was not made on the basis of perceived technical superiority among the competing reactors. This selection was made because of the similarity in size to the majority of large PWRs potentially available for plutonium disposition. Large, existing BWRs that do not need license extensions to complete the plutonium disposition mission could also be used in this alternative.

The transition to full MOX cores within a reactor (MOX in each fuel bundle) will be accomplished incrementally. At the start of the reactor portion of the mission, 44% of the reactor core will have the LEU fuel bundles replaced (one core reload) with MOX fuel bundles. Approximately 18 months later (one fuel cycle), another 44% of the core will have the LEU fuel bundles replaced with MOX bundles. At the end of the next fuel cycle, the remainder of the reactor core will be loaded with MOX fuel bundles. The transition from MOX fuel to LEU fuel at the end of the plutonium disposition mission will be accomplished in reverse order, of the MOX core being replaced with LEU fuel after each fuel cycle.

The power rating of the reactor chosen for the plutonium disposition mission, coupled with the reactor core design and burnup, establish the plutonium throughput for the reactors. This value, in turn, establishes the throughput for all upstream operations.

The top-level flow diagram, Fig. 2.2, shows the four major facilities in this alternative: PuP facility, MOX fuel fabrication facility, reactor facilities, and HLW repository. The diagram shows the plutonium flow through the four major facilities.

2.1.1 General Assumptions

- The inventory of surplus plutonium is 50 MT. The surplus plutonium currently exists in a variety of forms: "pits" from dismantled nuclear weapons, pure and impure metal, pure and impure plutonium oxide (PuO_2), alloys, unirradiated reactor fuels, and PuO_2 and uranium oxide (UO_2) materials.
- Alternatives were designed to address the entire inventory. This does not necessarily mean that all material will ultimately channel through the same set of operations, only that any alternative had to provide a disposition path for all surplus material.

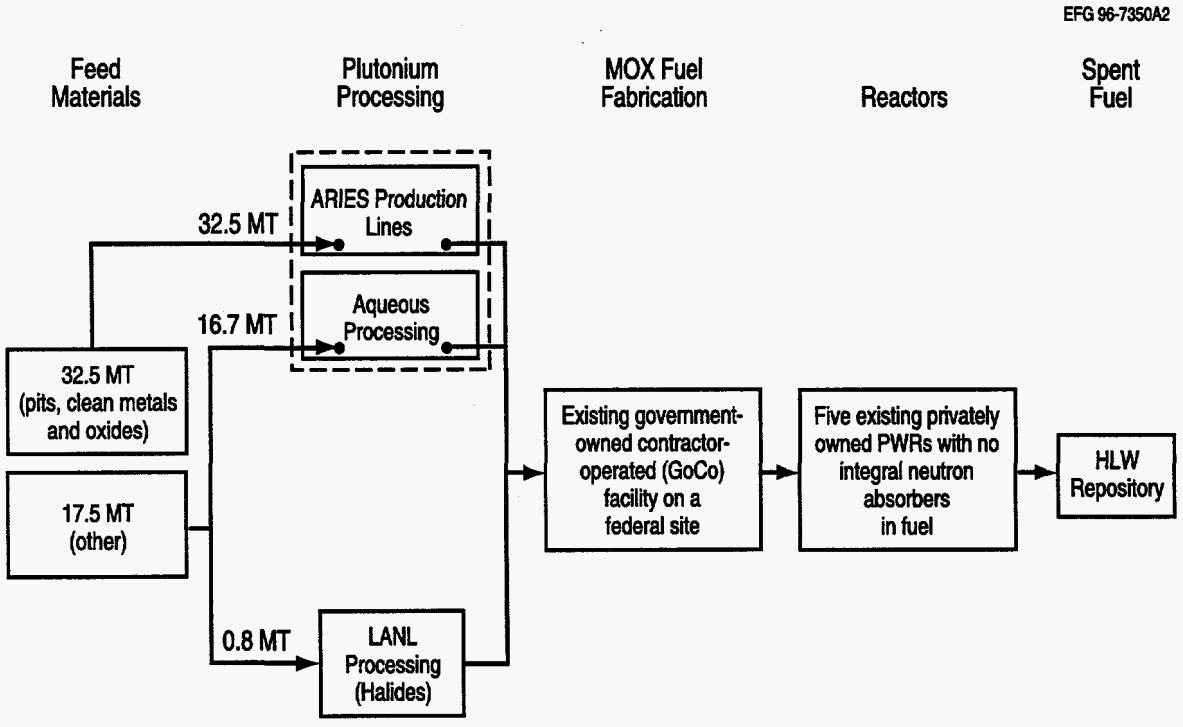

Figure 2.2. Top-level flow diagram for the existing LWR

- Disposition of the plutonium will begin within ~10 years and be completed within ~25 years after the ROD. Authorization for initiation of the line item funding process coincides with the ROD.
- All necessary operations to implement a disposition alternative (e.g., design, construction, licensing, operations, D&D, storage, transportation, S&S, inspections, and packaging operations) from the inception of the program until disposition to the SFS are included. Additionally, the impacts associated with emplacement in an HLW repository are assessed.
- Adequate funding will be available, when required, to support the design and construction of the chosen disposition alternatives.
- Facilities will comply with applicable federal, state, and local laws and regulations and DOE orders.
- Schedules presume legislation is available to support implementation of the alternatives. In all cases considered in the Fissile Material Disposition Program, some legislation will be required to enable the disposition alternatives to be implemented.
- While pending disposition to the SFS, the plutonium must meet the Stored Weapons Standard, as the term was coined by the NAS and as specified in DOE orders and guides.
- All operations involving surplus plutonium will be performed under International Atomic Energy Agency (IAEA) safeguards, except those involving classified parts, shapes, and information.
- An HLW repository will be available to accept spent MOX fuel.
- The Waste Isolation Pilot Project (WIPP) will be available to accept small amounts of transuranic (TRU) wastes generated in the PuP operations.
- Waste minimization and pollution control principles consistent with DOE policy will be applied in the design considerations of each technology.
- Schedule and cost assumptions and bases are discussed in Appendixes B and C, respectively.

2.1.2 Summary Description of Base-Case Variant Disposition Facilities

The following facilities are included in this alternative:

PuP Facility—The analysis assumes that the baseline PuP facility is located in an existing facility at a federal site. The plutonium pits and clean metal (~32.5 MT of plutonium) would be processed by the Advanced Recovery and Integrated Extraction System (ARIES) hydride-dehydride/oxidation (HYDOX) dry processing procedure, and the other feed material (~16.7 MT of plutonium) would be processed by an aqueous process. A small amount of halide-contaminated plutonium (0.8 MT) is assumed to be processed at available facilities at Los Alamos National Laboratory (LANL). The end product of the PuP facility is PuO_2 that meets the specifications for feed to the MOX fuel fabrication facility. The PuP facility will be subject to external review by the Defense Nuclear Facilities Safety Board (DNFSB).

MOX Fuel Fabrication Facility—A federally owned MOX fuel fabrication facility located in an existing building on an existing federal site will receive the oxide, rod and bundle components, depleted UO_2, and additives for fabrication of MOX fuel; perform the assembly of fuel bundles; and ship the fuel to the existing LWRs. This facility will be licensed by the Nuclear Regulatory Commission (NRC).

Existing LWRs—Five existing 3411-MW(t) [1150-MW(e)] PWRs will irradiate the MOX fuel. The irradiation will transform the MOX fuel to meet the SFS. After irradiation, the fuel will be stored on site and subsequently moved to the high-level waste (HLW) repository.

HLW Repository—The HLW repository will receive the spent fuel in large canisters, transfer the sealed canisters to disposal casks, and move the casks underground for emplacement.

The HLW repository is included here for completeness because the spent fuel will ultimately be emplaced in a geologic repository. Emplacement in the geologic repository, however, is not required to achieve the SFS.

Each facility must provide acceptable material to the follow-on facility in a timely manner to meet the desired mission schedule. PuO_2 from the PuP facility will be required to fabricate MOX fuel for use in the reactors. After cooling for 10 years in the spent fuel pool at the reactor facility, spent fuel will then be sent to the HLW repository. Figure 2.3 shows the proposed schedule for the PuO_2 processing and MOX fuel production, as well as the fuel loading schedule for the reactors. Figure 2.4 shows the MOX fuel assembly processing schedule, the fuel loading schedule, and the schedule for sending spent fuel to the repository.

Additional detail is provided on the individual facilities in the remainder of this chapter.

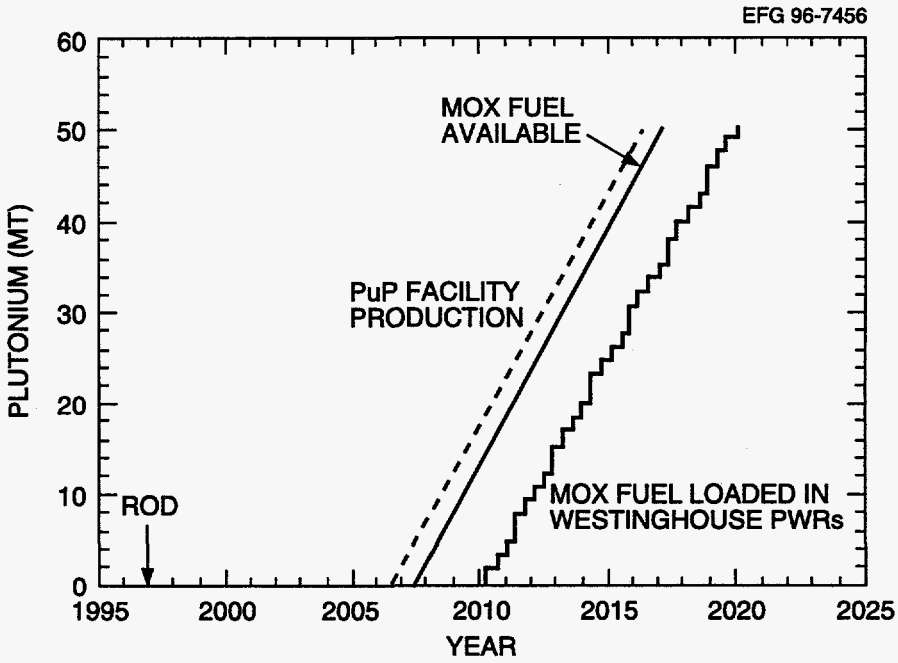

Figure 2.3. Plutonium dispositioning schedule

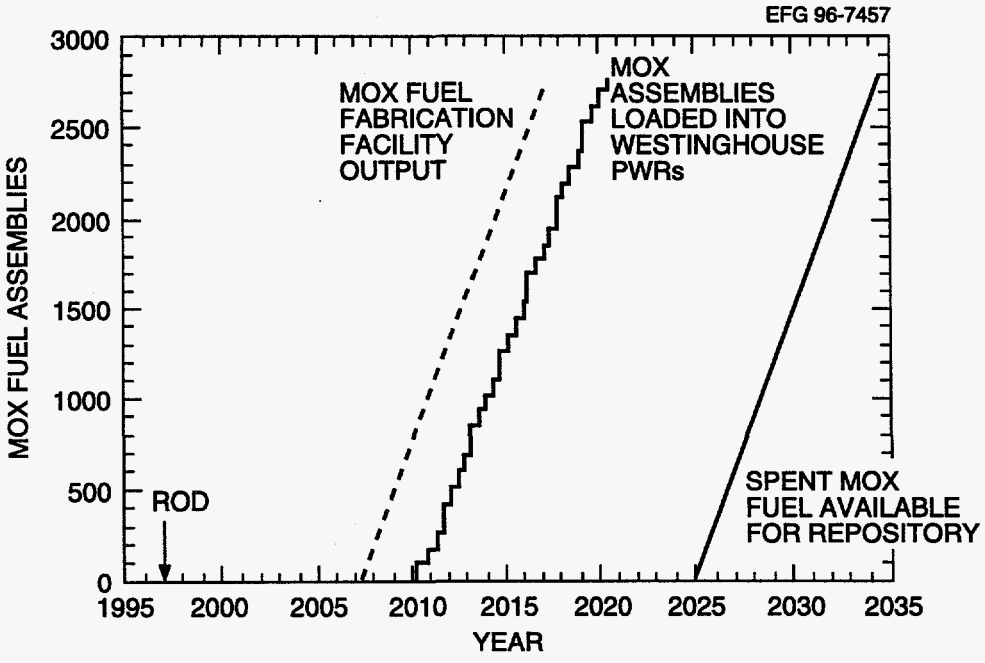

Figure 2.4. MOX fuel assembly processing schedule

2.1.3 Description of Facility Interfaces for the Base-Case Variant Disposition

Multiple facilities are required for disposition of ~50 MT of excess weapons-usable plutonium as MOX fuel in existing LWRs. Between each facility are a series of sequential movements of the plutonium from its current locations (storage vaults at a number of DOE facilities) through the various processing, fabrication, and reactor facilities, and ultimately, to emplacement as spent fuel at an HLW repository. Figure 2.5 provides a simplified flow chart of the transportation segments associated with the existing LWR disposition alternatives. Actual plutonium processing and fabrication facility locations will be determined by DOE following the ROD.

For analysis purposes, it has been assumed for the existing LWR base case that the excess plutonium is in interim storage at many locations within the DOE weapons complex. This material will first be packaged and transported to a plutonium processing facility [assumed for analysis purposes to be located at the Savannah River Site (SRS)], where the material is converted to PuO_2. The PuO_2 will then be repackaged and transported to the MOX fuel fabrication facility plant (assumed for analysis purposes to be constructed in an existing building elsewhere at SRS). Once fabricated, the fresh MOX fuel will be packaged and transported to five existing LWRs that have been modified to operate on MOX fuel. Spent fuel discharged from each reactor will first be stored in spent fuel pools at each reactor for 10 years. Ultimately, the spent fuel will be packaged and transported to an HLW repository for emplacement.

2.2 PuP Facility

2.2.1 PuP Facility Description

The PuP facility will receive surplus material from the various sites in the DOE complex and convert it to a form suitable for feed to the MOX fuel fabrication

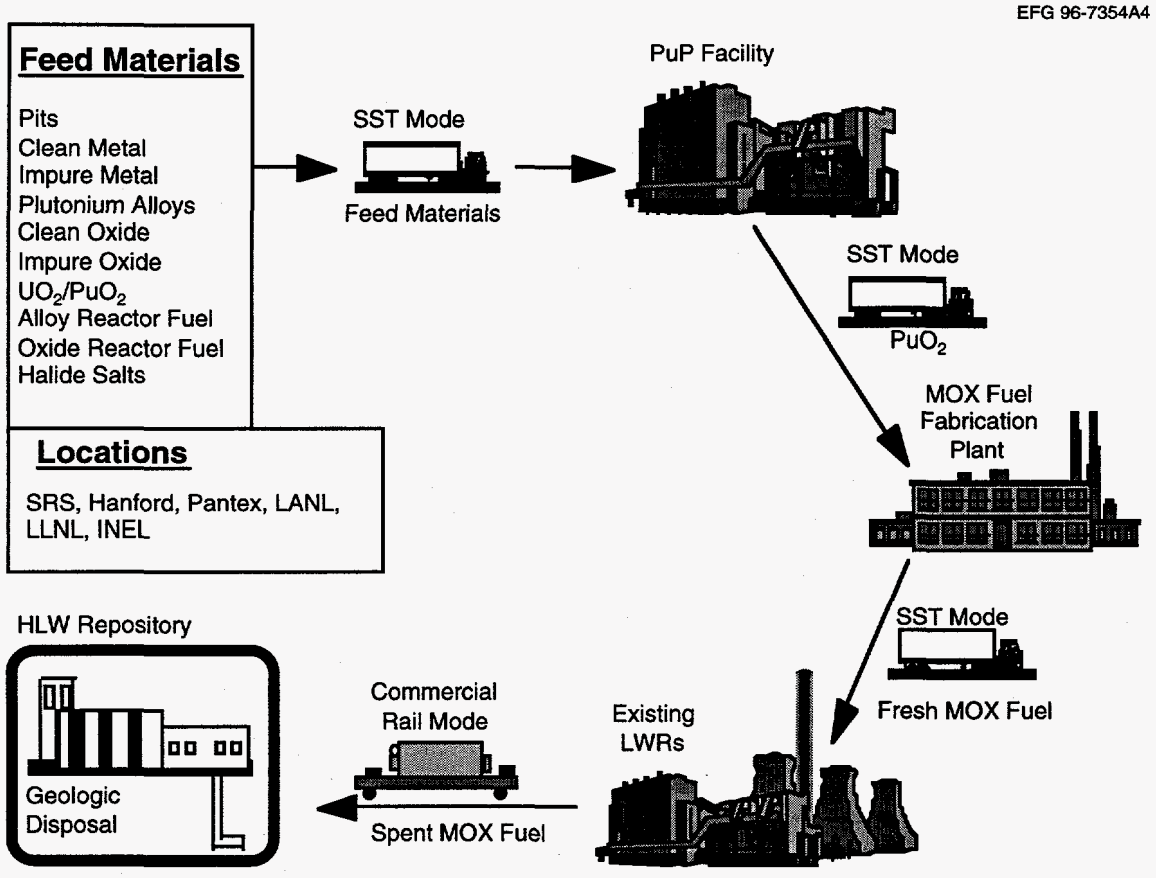

Figure 2.5. Simplified flowchart showing transportation segments for the existing LWR alternative

facility. Surplus fissile materials to be processed include pits, clean and impure metal, plutonium alloys, clean and impure oxide, uranium/plutonium oxides, unirradiated plutonium alloy reactor fuels, unirradiated oxide reactor fuels, and halide salts. Pits and clean metal will be converted to PuO_2 using the ARIES (HYDOX) process. A large fraction of the gallium will be removed, if necessary, using a thermal treatment process; the resulting oxide will be packaged, assayed, and stored awaiting shipment to the MOX fuel fabrication facility. If thermal processing proves to be inadequate for reducing gallium concentration to acceptable levels, aqueous processing will be used. Impure oxides will be dissolved, purified using ion exchange or solvent extraction, precipitated, and calcined. The oxide product will then be packaged, assayed, and stored with the oxide from pits and clean metal. Alloy and oxide reactor fuel must be disassembled and declad before processing.

The analysis assumes that the PuP facility will be located in an existing building on one of several existing federal sites. One such candidate is Building 221-F located at SRS in the F-canyon area. Space has been identified that could be adapted for the plutonium disposition mission without interfering with ongoing operations. It is assumed that the 32.5 MT of pits and clean metal (throughput of 3.25 MT/year for 10 years) will be processed using the ARIES (HYDOX) dry method in the current plutonium storage facility/new special recovery (PSF/NSR) area on the fifth level of Building 221-F. The aqueous equipment (gloveboxes, dissolvers, furnaces, etc.) currently housed in the PSF/NSR area would be moved to areas on the second and third levels of Building 221-F. This aqueous equipment, supplemented by some additional new equipment, would be used to process the 16.7 MT of mixed feed plutonium (throughput of 1.67 MT/year for 10 years). Based on estimates by SRS, the space required for processing the plutonium is just under 21,000 ft^2, which is within the space available for use without interfering with current canyon operations.

A small amount of halide-contaminated plutonium (about 800 kg) is assumed to be processed by specially designed aqueous chloride processing lines at existing facilities at LANL.

An additional location for possible use is the Fuel and Material Examination Facility (FMEF) on the Hanford reservation in Washington state. FMEF was initially designed to support the Fast Flux Test Facility (FFTF) for the production of MOX fuel. This facility has ~85,000 ft^2 of space and much of the needed equipment available.

After ROD, additional federal sites may also be considered for the PuP site location.

2.2.2 PuP Facility Design and Construction

2.2.2.1 PuP Facility Design and Construction Schedule

The duration and path of the design and construction tasks for the PuP facility are based on a generic DOE Major System Acquisition–Capital Construction Project. The design and construction process will begin at ROD with the start of the selection process for an architect-engineer (AE) firm. This contractor will be responsible for developing the required designs for the facility modifications and completing these modifications. Work on the conceptual design will begin as soon as the AE contractor has been selected. The first key decision (KD-1) to start work on the Title I design will be made after the conceptual design is complete and the initial line item funding has been approved. With the approval of the Title I design (KD-2) and final line item funding, work on Title II design will begin. The facility modifications and equipment procurement will start after Title II has been approved (KD-3). Equipment installation will proceed in a staged process so that the preoperational checkout of the facility will start 6 months before completion of the installation. The design and construction schedule is shown in Table 2.2 and as a part of Sect. 2.2.6.

Research, development, and demonstration (RD&D) of the various PuP technologies are currently under way. The prototype phase of ARIES is scheduled to begin in 1998. A 1-year site and facility selection process will begin after ROD to determine the most appropriate existing facility on a federal site for the PuP production facility.

2.2.2.2 PuP Facility Design and Construction Cost

This category represents the bulk of the up-front or investment costs for the PuP facility; in government accounting terms it is called *total estimated cost* (TEC). It also represents the line item funding appropriated by Congress. TEC is covered under categories 7–12 in the table appearing in Appendix C

Table 2.2. PuP facility design and construction schedule

Task name	Duration (months)	Start	Finish
R&D Funding Available			10/1995
FMDP ROD			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Initial Funding Process	24	12/1996	12/1998
Final Funding Approval	12	12/1998	12/1999
RD&D	36	10/1995	10/1998
Site and Facility Selection	12	12/1996	12/1997
Design Process	61	12/1996	1/2002
AE Selection	3	12/1996	2/1997
Conceptual Design	24	3/1997	3/1999
Approval of New Start (KD-1)			3/1999
Title I	12	3/1999	3/2000
Approval to Commence Title II (KD-2)			3/2000
Title II	22	3/2000	1/2002
Facility Modification	48	1/2002	1/2006
Approval to Start Construction (KD-3)			1/2002
Construction, Procurement, and Equipment Installation	48	1/2002	1/2006

of this report. Research and engineering development (R&D), licensing, and other preoperational costs are discussed in Sect. 2.2.3.2.

The design and construction cost of the PuP facility is based on modifying existing facilities at a DOE site. The cost values determined for this option are specifically based on modifying Building 221-F in the F-canyon area at SRS and include using existing equipment and infrastructure.

The 1996 constant dollar design/construction cost for the PuP facility located in existing facilities at SRS is summarized in Table 2.3. The sum of the design and construction costs (categories 7–10), plus allowances for construction management and initial spares, is estimated to be $90M. The major cost components are $17M for engineering design and inspection, $34M for capital equipment (equipment necessary for feed materials receiving, pit processing, mixed feed processing, and facility modification), and $32M for direct and indirect construction required for site modification. An allowance for indeterminates (AFI) of $25M [27.8% of the sum ($90M)] has been included in the estimate. A risk contingency of $56M was included to account for the preliminary nature of the cost estimate. The total plutonium facility design and construction cost, including contingency, is $171M.

2.2.3 PuP Facility Oversight and Permitting

The licensing approach for the reactor-based plutonium disposition options is to satisfy the NAS ES&H criteria "that any disposition option to operate in the United States:

- should comply with NRC regulations governing allowable emissions of radioactivity to the environment, and allowable radiation doses to workers and the public, from civilian nuclear-energy activities;
- should comply with international agreements and standards covering the disposition of radioactive materials in the environment; and
- should not add significantly to the ES&H burdens that would be expected to arise, in the absence of the weapons-usable plutonium disposition, from

Table 2.3. PuP facility design/construction cost

Category	Cost category description	Plutonium processing at SRS [lump sum (1996 $M)]
	Capital or TEC front-end costs:	
7	Title I, II, III engineering, design, and inspection	17
8a	Capital equipment	34
8b	Direct and indirect construction/modification	32
9	Construction management	4
10	Initial spares	3
11	AFI	25
12	Risk contingency	56
	TOTAL (TEC)	$171

appropriate management of the environmental legacy of past nuclear-weapons production and from appropriate management of the ES&H aspects of past and future nuclear-energy generation."[1]

For those operations and processes conducted in existing or converted facilities owned by DOE as planned for the PuP facility, the regulation of nuclear activities and the protection of ES&H will be conducted under DOE regulations, safety guides, technical standards, directives, and compliance agreements with the oversight of the DNFSB, the Environmental Protection Agency (EPA) where applicable, and the state within which the facility is located. Such unlicensed DOE-owned facilities will be held to a standard of nuclear safety and quality equivalent to that of a facility licensed by the NRC. The mechanism for doing this is implemented through the regulations issued under the *Price-Anderson Amendments Act of 1988* and the *Atomic Energy Act of 1954*, as amended. All permitting requirements from applicable federal statutes will apply.

National Environmental Policy Act (NEPA)—The conversion and utilization of DOE-owned facilities for the plutonium disposition mission may require additional specific NEPA actions (under 10 CFR 1021.400) beyond the PEIS.

Atomic Energy Act of 1954, as amended (AEA)—Unlicensed DOE-owned facilities will be operated by qualified, responsible DOE contractors subject to the indemnification requirements of the *Price-Anderson Amendments Act of 1988* and therefore subject to the nuclear safety regulations issued under and the enforcement provisions of Sect. 234A of the *Atomic Energy Act of 1954*, as amended.

Applicable regulations include the DOE rules for nuclear safety and radiation protection as given in 10 CFR Parts 820, 830, 834 (draft), and 835; and for classifying certain DOE-owned nuclear materials as given in 10 CFR Part 962.

Comparability to licensed facilities will be achieved by enforcing contractually mandated compliance with appropriate safety guides and technical standards that implement the DOE regulations. These DOE technical standards are periodically reviewed and updated to be comparable to current NRC licensing requirements. Key technical standards currently applicable to plutonium operations in DOE nonreactor nuclear facilities include the following:

- DOE-STD-101-92, *Compilation of Nuclear Safety Criteria for Potential Application to DOE Nonreactor Nuclear Facilities*, March 1992;
- DOE-STD-3009-94, *Preparation Guide for U.S. DOE Nonreactor Nuclear Facility Safety Analysis Reports*, July 1994; and
- DOE-STD-3013-94, *Criteria for Safe Storage of Plutonium Metals and Oxides*, December 1994.

These DOE standards implement requirements for handling, processing, and storage of special nuclear materials (SNMs) consistent with or analogous to pertinent portions of 10 CFR Parts 70, 71, 73, and 74. These DOE standards also incorporate by reference pertinent NRC technical and regulatory guidance from the Division 3 series (Fuels and Materials Facilities) and other relevant portions of the NRC regulatory guides as well as industry standards.

A clear path forward exists, and regulatory criteria and guidance are available to define an appropriate strategy and plan for satisfying DOE regulations. Transportation of SNMs to and from the PuP facility will be done in accordance with NRC regulations in 10 CFR Part 71, Department of Transportation (DOT) regulations in 49 CFR Parts 171–179, and (for wastes) EPA regulations in 40 CFR Part 263.

Resource Conservation and Recovery Act (RCRA)—*Plutonium disposition represents no new or special permitting situation in regard to compliance with RCRA for treatment or disposal of hazardous waste.* However, as a DOE program, all facets of the plutonium disposition mission are subject to the waste minimization/pollution prevention policies of the president and the secretary of energy in regard to the plans required of waste generators under Sect. 3002(b) of RCRA. Such a plan will be developed and implemented consistent with EPA guidelines published in the *Federal Register*. Special attention will be directed to avoiding the accumulation of hazardous and mixed wastes (MWs) without treatment options so that exemption requests to the enforcement provisions of Sect. 3004(j) of RCRA can be avoided.

A clear path forward exists, and regulatory criteria and guidance are available to define an appropriate strategy and plan for satisfying DOE regulations.

Clean Air Act and Clean Water Act—New permits may be required if existing permits cannot be amended; however, *no new or unusual permitting situations or special requirements are anticipated.*

2.2.3.1 PuP Facility Oversight and Permitting Schedule

For this analysis, it has been assumed that the DNFSB oversight review will start at ROD with the site selection process and will require 5 years. The NEPA process and other site-specific permitting will require 3 years and will start after the site has been selected. The oversight and permitting schedule is shown in Table 2.4 and as a part of Sect. 2.2.6.

2.2.3.2 PuP Facility Operating-Funded Project Cost

This section discusses life cycle cost (LCC) categories 1–6 in the 24-category estimating format described in Appendix C. These six categories, which include oversight and permitting, constitute what is termed preoperational or *operating-funded project cost* (OPC). OPC is the portion of the *total project cost* (TPC, investment, or up-front cost) budgeted with operating dollars rather than congressional line item capital or TEC dollars. Because this facility is likely to be government-owned and -funded, this distinction is important.

OPC generally includes the majority of the preconstruction activities and many of the startup activities carried on by the operating contractor before full-capacity operation of the facility and after construction is complete.

All preoperational costs, including costs for oversight, are discussed in this section. These costs are consistent with siting the PuP facility in an existing facility (Building 221-F) at SRS, as discussed in Sect. 2.2.1. The preoperational costs are summarized in Table 2.5.

Table 2.4. PuP facility oversight and permitting schedule

Task name	Duration (months)	Start	Finish
Oversight and Permitting	60	12/1996	12/2001
DNFSB Reviews Existing DOE Facility	60	12/1996	12/2001
Environmental/NEPA/DOE	36	12/1997	12/2000

Table 2.5. PuP facility preoperational costs including oversight and permitting

Category	Cost category description	Plutonium processing at SRS [lump sum (1996 $M)]
	Preoperational or OPC up-front costs:	
1	R&D ($40M at SRS; $41M at LANL)	81
2	NEPA, oversight, permitting	6
3	Conceptual design	3
4	QA, site qualification, and S&S plans (included in category 2)	0
5	Postconstruction startup	50
6	Risk contingency	11
	TOTAL OPC	$151

The cost for R&D is estimated to be $81M, which includes $40M for the necessary R&D at Savannah River and includes $41M for continued R&D at LANL for ARIES. The cost for NEPA, oversight, and permitting is estimated to be $6M. This category 2 cost also includes the charges that would normally be included in category 4 [quality assurance (QA), site qualification, and S&S plans]. The conceptual design cost required for the facility modification is estimated to be $3M. Postconstruction startup costs at SRS are estimated to be $50M. A contingency of $11M was allowed (~11% of the total of the SRS portion of the R&D cost, the oversight cost, the conceptual design cost, and startup cost). The total 1996 constant dollar preoperational cost, including contingency, is $151M, as indicated in Table 2.5.

2.2.4 PuP Facility Operations

2.2.4.1 PuP Facility Shipment and Storage

The surplus plutonium feed materials will be packaged and transported from their current locations to the PuP facility, where they will be converted to PuO_2. Once in oxide form the material will be repackaged and stored in vaults until it is needed by the MOX fuel fabrication facility. The PuP facility will operate over a shorter period (generally 10 years), while the MOX fuel fabrication facility will probably manufacture fuel over a period that coincides with the existing LWR fueling requirements. The required lead/lag storage vaults will be constructed at both the PuP facility and the MOX fuel fabrication facility.

Excess weapons-usable materials located at various DOE facilities include pits, clean metal, impure metal, plutonium alloys, clean oxide, impure oxide, uranium/plutonium oxide, alloy reactor fuel, oxide reactor fuel, and halide salts and oxides. Because of the variety of materials involved, no single Type B package design is appropriate. Therefore, DOE will use a number of different package designs for the packaging and transport of the feed materials to the PuP facility. Shipment will be by safe, secure trailer (SST). Each SST will transport between 28 and 35 packages with approximately three SSTs per convoy. Table 2.6 summarizes estimates of the numbers of packages and shipments required for this shipment leg.

2.2.4.2 PuP Facility Process

A diagram and a depiction of the PuP facility process flow are shown in Figs. 2.6 and 2.7, respectively. The

Table 2.6. Parameters for feed materials transport leg

Maximum plutonium material/package (kg)	Quantity of plutonium/campaign (kg)	Estimated number of packages to be shipped	Number of SST shipments/campaign
4.5	50,000	31,000[a]	1,100

[a]The quantity of material included in each package will vary. The estimated number of shipments is based on an average shipment weight.

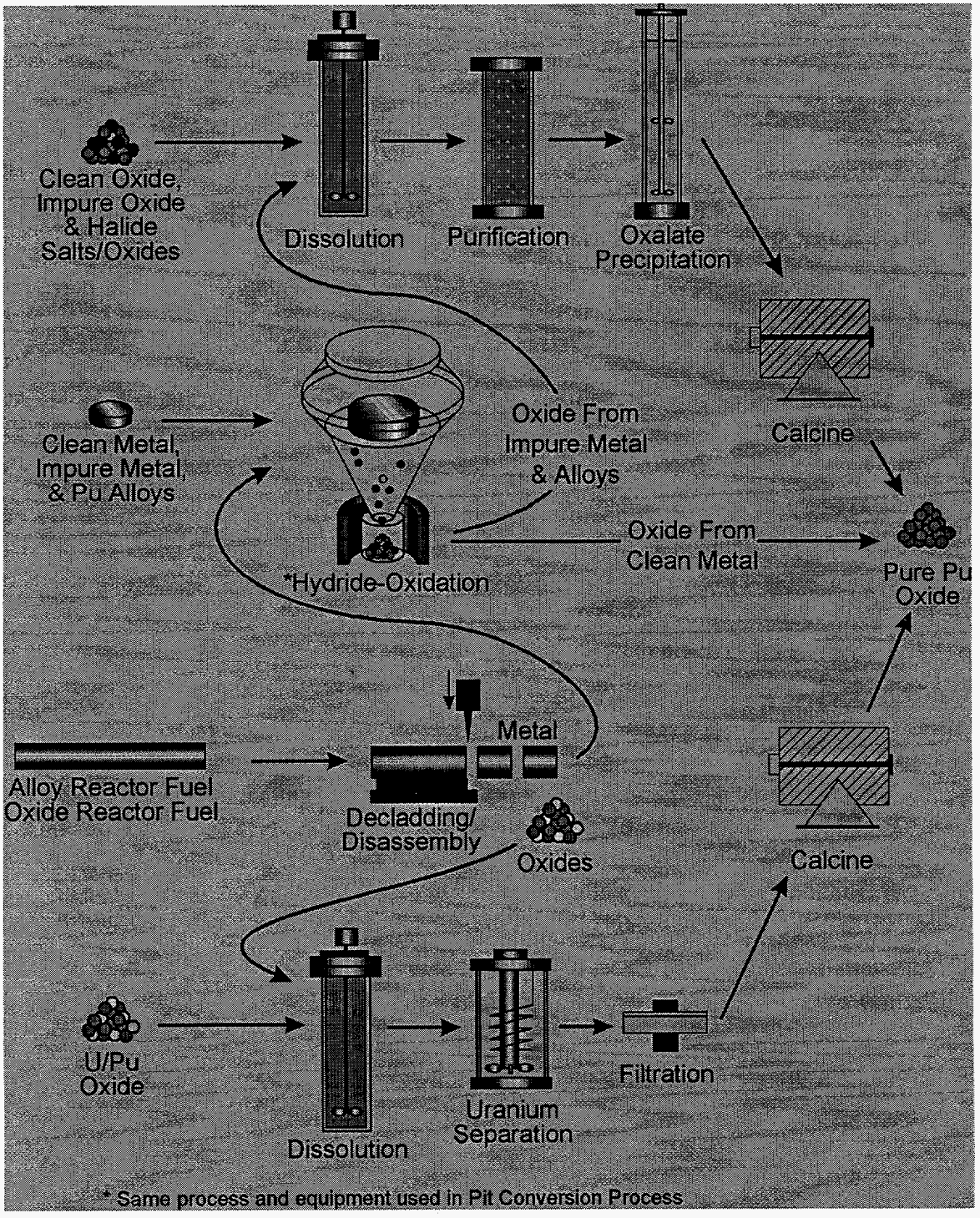

Figure 2.6. Process flow depiction for the PuP facility. Note: This figure is not meant to convey the actual process flow of the PuP facility, only to show the kinds of process steps that will be used.

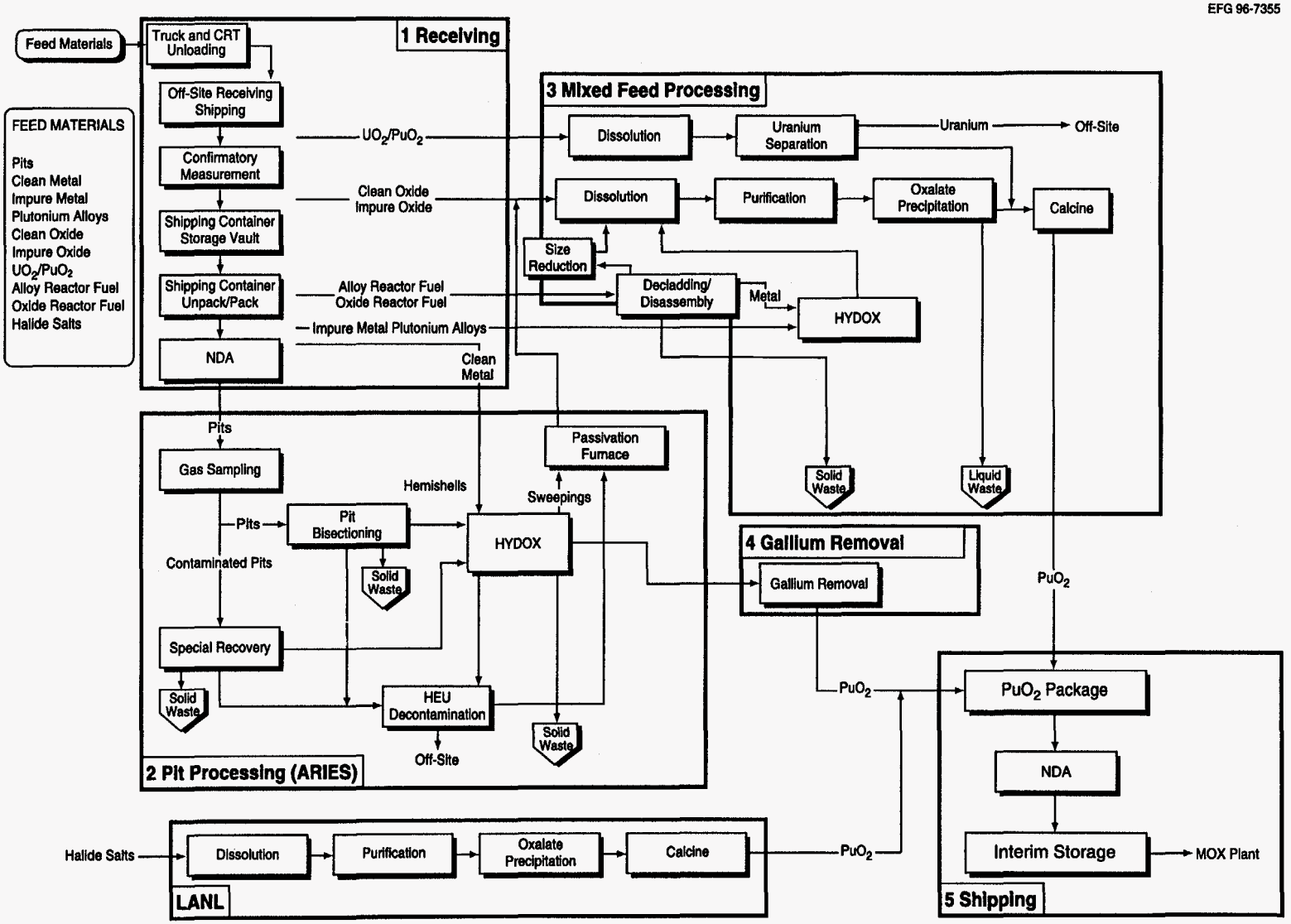

Figure 2.7. Process flow diagram for the PuP facility

facility has five major processing and handling sections: receiving, pit processing, mixed feed processing, gallium removal, and shipping.

Receiving—In the receiving area, pits and mixed plutonium feed stocks will be received by truck. In addition to plutonium pits in their shipping containers, other plutonium forms will be received in a variety of certified transport packages. Shipping containers aboard SSTs will be unloaded by forklifts onto a secured dock. The shipping containers will be inspected, checked for contamination, and unpacked.

Storage vaults will be required for empty shipping containers and primary pit storage containers. In-line nondestructive assay (NDA) equipment will be used to establish the plutonium content of all materials received.

Pit Processing (ARIES)—All pits will be gas-sampled to check for potential contamination. Contaminated pits will be sent to special recovery; noncontaminated pits will be sent to the standard disassembly station. Noncontaminated pits will be opened using a simple pit bisector and converted to PuO_2 using the ARIES (HYDOX) process. Clean metal will also be converted to oxide using this process. Contaminated pits will be decontaminated, and the plutonium-bearing components will be converted to PuO_2.

A passivation furnace will be used to convert glovebox sweepings to stable oxides, after which the oxide will be routed to the mixed feed processing stream. A PuO_2 packaging station will be provided to remove the PuO_2 from the glovebox.

Mixed Feed Processing—These streams include the remaining portion of the plutonium feed material. These feed streams will be processed primarily by aqueous means. The aqueous process includes the following steps: dissolution, purification (by solvent extraction or ion exchange), oxalate precipitation, and calcination. The clean and impure oxide streams will enter the aqueous process without additional preparation. However, the alloy reactor fuel and oxide reactor fuel must first go through a decladding/disassembly and size reduction procedure, and the impure metal and plutonium alloys will proceed through the ARIES (HYDOX) process before entering the aqueous processing line.

Halide salts will be converted to PuO_2 using an existing aqueous processing line at LANL.

Gallium Removal—A substantial fraction of gallium will be removed from the PuO_2 via a thermal treatment process. If necessary, the PuO_2 will be reconditioned to meet MOX fuel feed specifications.

Shipping—PuO_2 will be packaged in appropriate certified packages specifically designed for shipment of oxide. A final assay of the processed material will be completed using nondestructive testing. The packages will then be placed in interim storage until transported to the MOX fuel fabrication facility.

2.2.4.3 PuP Facility Operations Schedule

The preoperational checkout of the PuP facility will start 6 months before the equipment installation is complete and will require 1 year. The facility is scheduled to operate for 10 years with an annual plutonium throughput of 5 MT. The first PuO_2 will be available for shipment 2 months after the start of operation. The operational schedule is shown in Table 2.7 and as a part of Sect. 2.2.6.

Table 2.7. PuP facility operational schedule

Task name	Duration (months)	Start	Finish
Preoperational Phase	12[a]	8/2005[a]	7/2006[a]
Operation	120	7/2006	7/2016
Approval to Commence Operation (KD-4)			7/2006
PuP Duration	120	7/2006	7/2016
First PuO_2 Available	2	7/2006	9/2006

[a]The dates for scheduling may fall anywhere within the month indicated. Task durations are rounded to the nearest month.

2.2.4.4 PuP Facility Operations Cost

Operations costs for the PuP facility consist of the cost of staffing and consumables for the 10 years of plutonium operations, waste handling, fees, capital upgrades, transportation, and oversight. These costs are reflected in categories 13–19 and 23 of the 24-category format. These costs are often called recurring costs because the annual costs tend to remain almost constant over the plant lifetime for a given production rate (in this case 5 MT of plutonium/year).

The annual operating cost and staffing requirements for processing 5 MT of plutonium per year at a modified facility (Building 221-F) at SRS are included with the annual "other LCCs," including operating costs, shown in Table 2.8. This table presents annual costs, as well as 10-year lump-sum values, in 1996 constant dollars. The annual operating cost, the sum of categories 13 and 14, was estimated to be $78.5M. Of this annual amount, $70M/year is assumed to be related to staff. At an average full-time equivalent (FTE) loaded salary of $77,900/year, the total staff count is 899 FTEs. This value was based on a required direct staff of 344, which included 156 operators, 55 radiological control officers, 12 systems engineers, 35 systems maintenance workers, and 86 analytical laboratory support personnel. In addition, the annual operating cost includes allowances for 555 FTEs representing indirect staff, site general and administrative (G&A) staff, and security personnel. The annual operating cost also includes some consumables and a few capital replacements at $8.5M/year.

A value of $6.6M/year was estimated for waste handling and disposal, and $1M/year was included for oversight charges. Two percent of the sum of these costs (categories 13–17) is allowed for management and operating (M&O) contractor fees ($1.7M/year), and 1% ($0.9/year) is allotted for payment-in-lieu-of-taxes (PILT) to the local communities.

Decommissioning costs are also included under other LCCs and are discussed in Sect. 2.2.5.2. A value of $169M is estimated for this activity. A value of $35M was estimated for transporting the plutonium feedstock from the various storage locations to SRS over the 10-year operating period. In addition to the above SRS processing costs, about $1M over the 10-year period is estimated for processing 800 kg of halide-contaminated plutonium at LANL. As shown in

Table 2.8. PuP facility other LCCs

Category	Cost category description	Plutonium processing at SRS and LANL	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 10		
	Other LCCs:		
13	O&M staffing	700	70.0
14	Consumables including utilities	85	8.5
15	Major capital replacements or upgrades (in category 14)	0	0.0
16	Waste handling and disposal	66	6.6
17	Oversight	10	1.0
18	M&O contractor fees	17	1.7
19	PILT to local communities	9	0.9
20	D&D	169	Nonrecurring
23	Transportation of plutonium forms to facility	35	3.5
24	Storage of plutonium at existing 94-1 site facility	Not in scope	
	PuP at LANL (halides)	1	0.1
	TOTAL OTHER LCC	$1092	$92.3

Table 2.8, the total "other LCC" estimate for the 10-year PuP campaign is $1092M.

2.2.5 PuP Facility D&D

The PuP facility will be constructed for the sole purpose of dispositioning surplus plutonium identified by this program. At the completion of this mission the PuP facility will be promptly decontaminated and decommissioned.

2.2.5.1 PuP Facility D&D Schedule

D&D is projected to require 2 years for removal of contaminated equipment and return of the building to habitable condition.

2.2.5.2 PuP Facility D&D Cost

The cost for decommissioning the PuP facility was estimated to be $169M and is included in Table 2.8.

2.2.6 PuP Facility Schedule Summary

The overall PuP facility implementation schedule is summarized in Table 2.9 and shown in Fig. 2.8. This facility schedule is also shown in the discussion of the overall alternative schedule in Sect. 2.6.1. This schedule does not include any contingency for delays caused by site selection difficulties, redesign, construction delays, or a delay in the approval of line item funding.

The critical path through the development of this facility is through the design and construction process. If the schedule for any task in the design and construction process is delayed, the rest of the implementation process will also be delayed. This critical path is illustrated in Fig. 2.8. If the start of operations at the PuP facility is delayed by more than 3 months, the start of operations at the MOX fuel fabrication facility will also be delayed, because the PuO_2 will not be available to begin fuel fabrication.

2.2.7 PuP Facility Cost Summary

Table 2.10 shows a summary of the PuP facility LCCs in the 24-category format. All anticipated plutonium-related costs from FY 1997 forward are included in this table. Section 2.6.2 of this report compares these LCCs with those for other facilities needed to complete the program mission for the base case. The total LCC for this facility is slightly over $1.4B.

2.2.8 PuP Facility S&S Summary

DOE and its predecessor agencies have successfully managed safeguards and security of SNMs for several decades. DOE maintains an impeccable record of providing adequate measures to ensure against theft or unauthorized access to SNMs. These measures include physical security, material accountability, inventory safeguards, and other technologies. These measures have been applied to SNMs in a variety of material

Table 2.9. PuP facility schedule summary

Task name	Duration (months)	Start	Finish
R&D Funding Available			10/1995
FMDP ROD			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Research, Development, and Demonstration	36	10/1995	10/1998
Site and Facility Selection	12	12/1996	12/1997
Oversight and Permitting	60	12/1996	12/2001
Design Process	61	12/1996	1/2002
Facility Modification	48	1/2002	1/2006
Preoperational Phase	12	8/2005	8/2006
Operation	120	8/2006	8/2016
D&D	24	8/2016	7/2018

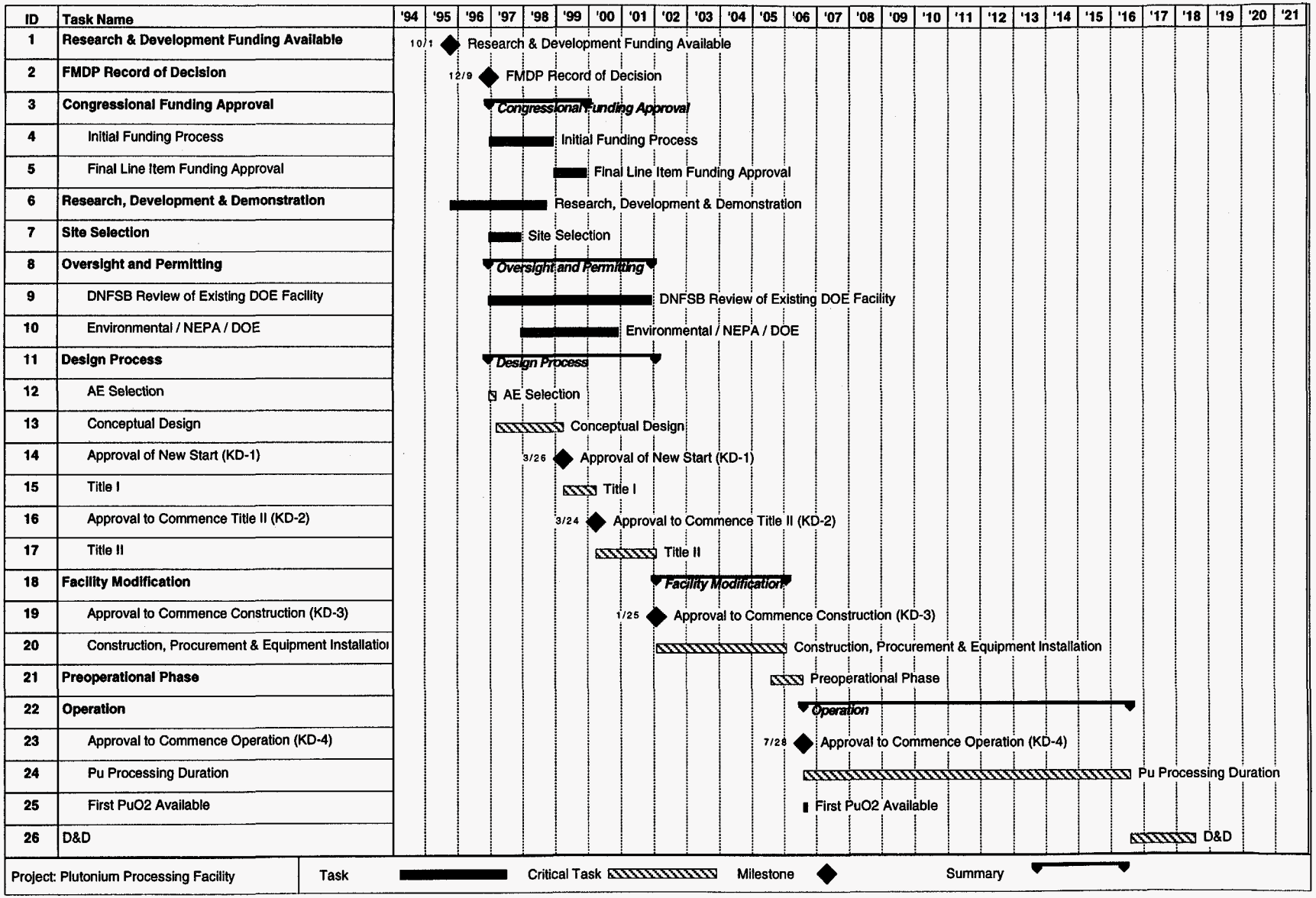

Figure 2.8. PuP facility schedule summary

Table 2.10. Summary of PuP facility LCCs

Category	Cost category description	PuP at SRS and LANL	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 10		
	Preoperational or OPC up-front costs:		
1	R&D ($40M at SRS; $41M at LANL)	81	
2	NEPA, licensing, permitting	6	
3	Conceptual design	3	
4	QA, site qualification, S&S plans	0	
5	Postconstruction startup	50	
6	Risk contingency	11	
	TOTAL OPC	$151	
	Capital or TEC front-end costs:		
7	Title I, II, III engineering, design, and inspection	17	
8a	Capital equipment	34	
8b	Direct and indirect construction/modification	32	
9	Construction management	4	
10	Initial spares	3	
11	AFI (percentage of categories 7–10)	25	
12	Risk contingency	56	
	TOTAL (TEC)	$171	
	SUBTOTAL UP-FRONT COST	$322	
12a	Plutonium processing at LANL (halides)	0	
	TOTAL UP-FRONT COST(TPC)	$322	
	Other LCCs:		
13	O&M staffing	700	70.0
14	Consumables including utilities	85	8.5
15	Major capital replacements or upgrades (included in category 14)	0	0
16	Waste handling and disposal	66	6.6
17	Oversight	10	1.0
18	M&O contractor fees	17	1.7
19	Payments-in-lieu-of-taxes to local communities	9	0.9
	RECURRING COST SUMMARY	$887	$88.7
20	D&D	169	Nonrecurring
21a	Revenues (if applicable) from sale of MOX or electricity	N/A	
21b	Revenue (if applicable) from sale of reactor	N/A	
22	Fees to privately owned facility	N/A	
23	Transportation of plutonium forms to facility	35	3.5
24	Storage of plutonium at existing 94-1 site facility	Not in scope	
	PuP at LANL (halides)	1	0.1
	TOTAL OTHER LCC	$1092	$92.3
	GRAND TOTAL ALL LCC	$1414	

forms, ranging from bulk SNM powders and solution to pits.

An assessment has been performed to identify where critical vulnerabilities might exist in operations or processes that make up the reactor disposition alternative. The purposes of the assessment were to (1) determine whether any inherent vulnerabilities exist that represent unique or novel threats to maintaining adequate measures against theft or unauthorized access and (2) identify any threats in the reactor disposition alternative operations that will require particular attention by facility designers to ensure that potential vulnerabilities are properly addressed.

This section discusses the vulnerabilities to theft and unauthorized access intrinsic to the material forms and processing environments in the plutonium processing facility. In the sense employed here, a "risk" is a set of conditions that require specific measures to ensure proper physical control of SNMs. *These risks should not be interpreted as the overall risk which the material will be subject to in the as-built facilities.* The overall risk in the as-built facility is driven to very small values by the S&S measures incorporated in the design and operation of the facility.

Possible Diversion, Theft, or Proliferation Risks—For this facility most of the material is in a very attractive form with minimal intrinsic barriers. A large number of processing steps provides increased opportunities for covert theft. Except for the tamper-protected containers in which the metal and/or oxide is placed, the material is fairly accessible. In addition, many of the processes involve bulk material and bulk accountability measurements. For a high-throughput facility this provides increased opportunity for covert theft, and the potential risk is high. In the case of an overt theft attempt, the targets of greatest concern would be the pits and pure metal and oxides, which are transportable. However, these materials would be under stringent protection, so the risk associated with an overt event would be acceptable.

Environmental Conditions—Table 2.11 provides process environmental conditions, material form, and other S&S information. The PuP facility involves a large number of processing steps with a relatively high throughput. Based on the quantity and attractiveness of the material, the facility will be a Category I facility (see Table 2.11). Waste streams containing fissile material will be generated and thus will require monitoring to prevent possible theft. Lag storage in a fairly active vault will be performed. There will be no intrasite transport movements [e.g., outside of the materials access area (MAA)]. SSTs will be used to deliver and pick up the material. Although durations of operations for a single batch (e.g., ~4.5 kg) are relatively short (8 h), a large number of batches will be needed to meet the 5-MT/year throughput; therefore, the window of opportunity for possible adversary actions is large.

Material Form—The material received at the PuP facility is the most attractive material for this particular alternative (e.g., pits, pure metal, and oxide). Table 2.12 provides the DOE attractiveness categories and quantities. In the case of pit conversion, the attractiveness category goes from IB to IC. For oxides and other high-grade material, the attractiveness level remains at IC. In some cases the feed material may be low-grade material, and the attractiveness may actually increase from IID to IC after processing. The material overall has very low intrinsic barriers. It is transportable. It has only a very low radiological barrier primarily (because of the presence of americium). It is in most cases in a very pure form, as a metal or oxide, and its isotopic composition makes it usable for a nuclear device. However, there are no new or unique (to DOE) material forms handled in the plutonium processing facility. A reasonable assumption, therefore, is that existing S&S design practices, material accountability and operating procedures, and facility protection approaches will result in acceptable process risk.

S&S Assurance—Material received into the PuP facility [e.g., pits and containers with tamper-indicating devices (TIDs)] would utilize item accountancy. Once the material has been removed from the container, bulk accountancy would be necessary. Many of the operations will involve hands-on activities, and the material is very accessible. The items being handled are not particularly large and do not require any special handling equipment. Most of the operations will be performed inside a glovebox. In addition to destructive assay, NDA would be performed. Because pits and other weapons material are being processed, some of the material will be classified. This may also apply to waste streams.

Potential Risks for Diversion—This facility will have several processing stages and will be handling large quantities of material. The high attractiveness of the material for this facility makes possible conversion and reuse easier, and because a lower level of effort is required to reuse this material, the ability to detect these covert activities is diminished. These factors

Table 2.11. Nonproliferation and S&S risk assessment for the existing LWR PuP base case facility

Environment								
Facility	**Activity**	**Duration (h)**	**Throughput**	**Waste streams**	**Maximum inventory**	**Intrasite transport**	**Number of processing steps**	**Barriers**
PuP			5 MT plutonium	Yes <0.1 g/L plutonium	0.5 MT plutonium	No	16	MAA
	Receiving, NDA, and unpacking	8	4.5 kg plutonium per batch (criticality limit)			No, SST unload	0	
	Pit processing	8				No	3	Glovebox
	Mixed feed processing	8	4.5 kg plutonium per batch			No	11	Glovebox
	Gallium removal	8	4.5 kg plutonium per batch			No	2	Glovebox
	Shipping, NDA, and unpacking	8	4.5 kg plutonium per batch			No, SST load	0	
Transport	PuP to MOX fuel fabrication facility							

Note: MAA—material access area.
NDA—nondestructive assay.

Table 2.11. Nonproliferation and S&S risk assessment for the existing LWR PuP base case facility (cont.)

Material form										
Facility	**Activity**	**SNM input**	**SNM output**	**Plutonium quantity**	**Concentration of plutonium**	**SNM* category**	**Item mass/ dimensions**	**Radiation barrier**	**Chemical composition**	**Isotopics**
PuP				Other fissile material present	Other fissile material	DUU				
	Receiving, NDA, and unpacking	Metal, oxide	Metal, oxide	4.5 kg per batch (criticality limit)	>0.9 g/g (<0.1 g/g) (other fissile material)	IB-IID	Shipping container DOT-6M, ACR8, AT400 (10–110 gallons)	No	Pure metal, oxides, miscellaneous	
	Pit processing	Metal	Metal			IB		No	Metal	
	Mixed feed processing	Metal, oxide, fuels, miscella-neous	Oxide	4.5 kg (per batch)		IC		No	Oxide, miscellaneous	
	Gallium removal	Oxide	Oxide	4.5 kg (per batch)		IC		No	Oxide	Mixed plutonium isotopes
	Shipping, NDA, and unpacking	Metal, oxide	Metal, oxide	4.5 kg (per batch)		IC		No	Oxide	
Transport	PuP to MOX fuel fabrication facility						Ship container, 50–55 gal drums			

Note: DUU—direct-use unirradiated.
*See Table 2.12.

Table 2.11. Nonproliferation and S&S risk assessment for the existing LWR PuP base-case facility (cont.)

S&S								
Facility	**Activity**	**Number of MBAs**	**Accounting system type**	**Nuclear measure methods**	**Classified material**	**Physically accessible**	**Access**	**Special handling equipment**
Plutonium processing		1–3	30% Item	Calorimetry, gamma, segmented gamma, neutron			Both remote and hands-on	No
	Receiving, NDA, and unpacking		Both	0.8% (domestic) 1.5% (international)	Yes	Yes No (pits, TIDs)		
	Pit processing		Item		Yes	Yes		
	Mixed feed processing		Bulk		Yes/No	Yes		
	Gallium removal		Bulk		No	Yes		
	Shipping, NDA, and unpacking		Bulk		No	Yes No (TIDs)		
Transport	PuP to MOX fuel fabrication facility							

Note: TID—tamper-indicating device.
MBA—material balance area.

Table 2.12. DOE attractiveness categories and quantities from DOE Order 5633.3B

	Attractiveness level	Plutonium and ^{233}U category (kg)			
		I	II	III	IV[a]
Weapons	A	All quantities	N/A	N/A	N/A
Pure products	B	≥2	≥0.4 < 2	≥0.2 < 0.4	<0.2
High-grade material	C	≥6	≥2 < 6	≥0.4 < 2	<0.4
Low-grade material	D	N/A	≥16	≥3 < 16	<3
All other materials	E	N/A	N/A	N/A	Reportable quantities

[a]The lower limit for Category IV is equal to reportable limits in this order.

must be anticipated and countered in the facility design by application of appropriate S&S measures.

Difficulty of Diversion, Retrieval, Extraction, and Reuse—The PuP facility involves very attractive material and high throughputs. The accessibility of the material, low intrinsic barriers, and large number of processing steps make the intrinsic risk of possible diversion high. If the material were to be diverted, the pure metal and oxide could be reused in a nuclear device relatively easily. Because pits and other material in this facility are classified, they would not be under international safeguards unless restricted data could be protected. Once again, however, similar or identical operations have been safely carried out for several decades in DOE facilities, and standard S&S measures are available to counter the intrinsic risks posed by material forms and process environments.

Assurance of Detection of Retrieval and Extraction—Because the PuP facility will involve large quantities of bulk material and very high throughputs, it may be difficult to detect (using material accountability alone) the diversion of a significant quantity of material. The presence of classified materials further complicates safeguards with respect to international inspection. Standard containment, surveillance, and other S&S measures can be employed to ensure that material is not being diverted.

2.2.9 PuP Facility Technical Viability

Five factors were evaluated to develop a qualitative assessment of the technical viability of a concept: a definition of the technological maturity of a process; the specification of the technical unknowns for the process and the technical risk associated with the application of the process; the R&D needs of the process; the condition, capacity, and reliability of infrastructure; and the regulatory and licensing requirements (previously discussed). Each of these items, except infrastructure, will be addressed in the following sections. A qualitative assessment of technical viability is presented in Appendix E.

Technological Maturity—Judging the maturity of the technologies employed in plutonium disposition facilities requires an assessment of the current level of development of each fuel cycle stage. Technologies can be categorized as being at the conceptual design stage, the laboratory or bench-scale testing stage (demonstrating scientific feasibility), the prototype stage (demonstrating engineering feasibility), or the industrialization/commercialization stage. Even if a significant domestic development base does not exist, a foreign experience base may be available.

All of the technology needed for pit disassembly and plutonium conversion exists at the laboratory and bench-scale testing stage and has been implemented to a limited degree. Ongoing R&D is moving the technologies to the prototype stage.

Technical Risks—Certain technologies have associated technical unknowns. Consequently, risks are associated with the application of the technologies based on these parameters.

The technical risks of the PuP facility are thought to be minimal. All processes have been demonstrated in existing facilities. The principal technical risk is the degree of reliability of these processes when applied at the level needed to achieve disposition goals. Throughput must be assessed; if it were found to be

insufficient, processes would have to be optimized. The precision and accuracy of assay measurements when conducted at the desired throughput levels remain to be determined.

R&D Needs—Various parameters were identified as unknown or poorly known for this alternative. The R&D necessary to address each of these technology development needs is presented subsequently.

The candidate plutonium disposition process requires PuO_2 as feed material. The baseline process for removing plutonium metal from pits, hydride/dehydride, produces a metal product. A reliable system to convert metal to oxide, ARIES, is a desired component of the Pit Disassembly Conversion Facility. An R&D project is required to develop and demonstrate a prototype PuO_2 production system.

The NDA subsystem for pits consists of four computer-based NDA instruments; a robot to load and unload the instruments; and a host computer to sense and control the instruments, schedule measurements, archive the results of the assays, and direct the activities of the robot. Integration of the instruments is untested. The reliability of the system and the precision and accuracy of the measurements remain to be determined. This information will permit the evaluation of the nuclear measurement requirements for the baseline processes in the facility and the effects of measurement requirements on the facility flow sheets.

The current DOE pit stockpile contains a variety of pit configurations. Some pits are relatively simple in design, whereas others are more complicated and difficult to disassemble. A relatively simple, inexpensive single-axis bisector has been developed for use with simple pit designs. This system must be tested and demonstrated as a part of an automated disassembly system that can process specified pit types more efficiently, with less wastes, and with reduced operator radiation exposure. Disassembly flow sheets must be generated for families of weapons components. Processes for handling the more complicated pit designs are currently under development and must be tested and demonstrated.

Nonpit conversion processes must be optimized to lower costs, improve throughput, and reduce wastes. The conversion processes that will have the most impact are the processing of plutonium reactor fuels and alloys, the dissolution and treatment of high-fired plutonium oxides, and the separation of impurities from plutonium-rich forms.

2.3 MOX Fuel Fabrication Facility

2.3.1 MOX Fuel Fabrication Facility Description

The MOX fuel fabrication facility will convert the PuO_2 from the PuP facility into MOX fuel to supply the existing LWRs. The MOX fuel fabrication facility will be federally owned and separate from the PuP facility (although it may be located at the same federal site).

The MOX fuel fabrication facility will receive PuO_2 from the PuP facility and produce fuel bundle assemblies. The feed oxide will be received, stored as needed, purified if required, milled, screened, and blended into lots. It then will be fabricated into pellets, the pellets fabricated into rods, and the rods assembled into bundles. The bundle assemblies will then be stored on site to await shipment to the existing LWRs.

The overall facility size for the annual throughput rate of 5100 kg of plutonium [118 MTHM (metric tons heavy metal)/year] will depend on the existing building ultimately chosen. (This building must have at least 80,000 ft^2 of contiguous, hardened floor space for process equipment.) A number of such buildings are being considered that are located on a federal site with plutonium-handling infrastructure. The MOX fuel fabrication facility annual plutonium throughput is based on planned reactor consumption. The MOX fuel fabrication facility will have a PuO_2 storage capacity of roughly 15 MT to enable reload and interim storage. Any additional storage will be located at either the PuP facility or another vault that is part of the DOE complex.

2.3.2 MOX Fuel Fabrication Facility Design and Construction

2.3.2.1 MOX Fuel Fabrication Facility Design and Construction Schedule

The duration and path of the design and construction tasks for the MOX fuel fabrication facility are based on a generic DOE Major System Acquisition–Capital Construction Project. The design and construction process will begin at ROD with the conceptual design, which will also begin the NRC licensing process. The 1-year site and facility selection process to determine the most appropriate existing facility on a federal site for the MOX fuel fabrication facility will start after the completion of the conceptual design. The selection

process for the M&O contractor will start after the intermediate approval for line item funding. This contractor will be responsible for developing the Title I and II designs and for completing the facility modifications required for the MOX fuel fabrication facility. Work on Title II will start after approval of the Title I design and the final line item funding. The facility modifications and equipment procurement will start after completion of Title II design and up to 1 year before the completion of the NRC licensing process. However, no safety-related construction may be done until after the license has been granted. The design and construction schedule is shown in Table 2.13 and as a part of Sect. 2.3.6.

2.3.2.2 MOX Fuel Fabrication Facility Design and Construction Cost

As previously discussed, this category represents the bulk of the up-front or investment costs for the MOX fuel fabrication facility and in government accounting terms is called TEC. It also represents the line item funding appropriated by Congress. In the Oak Ridge National Laboratory (ORNL) life cycle costing format, it is covered under categories 7–12 in the table appearing in Appendix C of this report.

Cost estimates for new or greenfield private facilities were modified for a MOX fuel fabrication facility employing new equipment installed in an existing building on a government site already having plutonium-handling infrastructure such as analytical laboratories, S&S, waste handling, etc. Many of the civil works costs for a new Category I building could be eliminated. It is assumed, however, that an existing building would need significant civil modifications to safely contain gloveboxes and other MOX fuel fabrication equipment.

For the MOX fuel fabrication facility supplying five large PWRs, a throughput capacity of 118 MTHM/year is needed. The following approach was used to calculate the TEC (sum of categories 7–12) for the MOX fuel fabrication facility for all reactor alternatives:

For all capacity up to 45 MTHM/year, the TEC = $200M. For *each* 45 MTHM/year of *additional capacity* above 45 MTHM/year, another $50M is added. Therefore, for a capacity of 118 MTHM/year, the TEC is $200M + (2) × $50M = $300M.

The MOX fuel fabrication facility TEC model and other models presented in this volume have been examined by a MOX fuel fabrication facility vendor and found to give reasonable estimates for a facility whose location and mission schedule have not yet been identified in detail.

The MOX economics model also partitions the TEC into the proper categories 7–12, as shown in Table 2.14. The design cost (category 7) includes Title I and II design and Title III inspection. It is calculated as ~23% of the sum of categories 8, 9, and 10. The capital equipment cost (category 8a) of $150M includes all of the new gloveboxes, process equipment, and auxiliary equipment. It is presumed that the MOX fuel fabrication facility process equipment will be purchased from, installed by, and tested by the private MOX fuel fabrication equipment vendor. It is estimated that $51M (category 8b) is needed for the modifications to the existing structure in order to house the MOX fuel fabrication equipment. This category also contains the indirect costs for the construction project, such as equipment rentals and QA. [It is assumed that a perimeter intrusion detection and assessment system (PIDAS) fence is already in place.] Category 9 (construction management) is subsumed in categories 8a and 8b. Category 10 (initial spares) is calculated as 8% of the process equipment cost and includes purchase of the necessary spare process-equipment items needed to keep the plant running during its early operating life. The AFI of $39M represents 15% of the sum of categories 7–10 and is considered reasonable for a facility that has undergone conceptual design in vendor studies. Category 12 (risk contingency) is designed to cover out-of-scope risks such as schedule delays and the need for redesign or retrofit of the facility.

2.3.3 MOX Fuel Fabrication Facility Licensing and Permitting

The MOX fuel fabrication facility, whether federally owned or privately owned, is assumed to be subject to NRC licensing.

Table 2.13. MOX fuel fabrication facility design and construction schedule

Task name	Duration (months)	Start	Finish
FMDP ROD			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Initial Funding Process	24	12/1996	12/1998
Final Funding Approval	12	12/1998	12/1999
Fuel Qualification Demonstration	60	4/1996	4/2001
Site and Facility Selection	12	12/1997	12/1998
Select M&O Contractor	12	12/1998	12/1999
Design Process	60	12/1996	12/2001
Conceptual Design	12	12/1996	12/1997
Title I	12	12/1999	12/2000
Title II	12	12/2000	12/2001
Facility Modification	36	12/2001	12/2004
Construction	36	12/2001	12/2004
Procurement	24	12/2001	12/2003
Equipment Installation	12	12/2003	12/2004

Table 2.14. Base-case MOX fuel fabrication facility design and construction costs

Category	Cost category description	118-MTHM/year throughput government MOX plant in existing building [lump sum (1996 $M)]
	Capital or TEC part of up-front cost:	
7	Title I, II, III engineering, design, and inspection (22% of categories 8a, 8b, 9, and 10)	48
8a	Capital equipment	150
8b	Direct and indirect construction/modification	51
9	Construction management (in categories 8a and 8b)	0
10	Initial spares (8% of category 8a)	12
11	AFI (15% of categories 7–10)	39
12	Risk contingency	0
	TOTAL (TEC)	$300

A clear path forward is provided in the existing licensing regulations promulgated by the NRC in regard to nuclear safety and radioactive waste management at MOX facilities. All permitting requirements from applicable federal statutes will apply.

The licensing approach for the reactor-based plutonium disposition options is to satisfy the NAS ES&H criteria "that any disposition option to operate in the United States:

- should comply with NRC regulations governing allowable emissions of radioactivity to the environment, and allowable radiation doses to workers and the public, from civilian nuclear-energy activities;
- should comply with international agreements and standards covering the disposition of radioactive materials in the environment; and
- should not add significantly to the ES&H burdens that would be expected to arise, in the absence of the weapons-usable plutonium disposition, from appropriate management of the environmental legacy of past nuclear-weapons production and from appropriate management of the ES&H aspects of past and future nuclear-energy generation."[1]

A clear path forward is provided in the existing licensing regulations promulgated by the NRC in regard to nuclear safety and radioactive waste management at MOX facilities.

NEPA—The construction and operation of a new NRC-licensed MOX fuel fabrication facility requires an Environmental Impact Statement (EIS) in accordance with 10 CFR 51.20(b)(7).

Atomic Energy Act of 1954, as amended—Operations subject to NRC licensing or authorizations at the MOX fuel fabrication facility include

- possession, handling, and storage of source material (10 CFR Part 40) and SNM (10 CFR Part 70) plus access authorizations to SNM (10 CFR Part 11);
- packaging and transportation of radioactive material (10 CFR Part 71); and, if applicable,
- land disposal of radioactive waste (10 CFR Part 61).

In each case, a clear path forward exists, and regulatory criteria and guidance, although somewhat dated and subject to review and revision, are available to define an appropriate licensing strategy and plan if required.

Transportation of SNMs to and from the MOX fuel fabrication facility will be done in accordance with NRC regulations in 10 CFR Part 71, DOT regulations in 49 CFR Parts 171–179, and (for wastes), EPA regulations in 40 CFR Part 263.

RCRA—*Plutonium disposition represents no new or special permitting situation with regard to compliance with RCRA for treatment or disposal of hazardous waste.* However, as a DOE program, all facets of the plutonium disposition mission are subject to the waste minimization/pollution prevention policies of the President and the Secretary of Energy with regard to the plans required of waste generators under Sect. 3002(b) of RCRA, and such a plan will be developed and implemented consistent with EPA guidelines published in the *Federal Register*. Special attention will be directed to avoiding the accumulation of hazardous waste and MW without treatment options so that exemption requests to the enforcement provisions of Sect. 3004(j) of RCRA can be avoided.

Clean Air Act and Clean Water Act—New permits may be required if existing permits cannot be amended; however, no new or unusual permitting situations or special requirements are anticipated.

2.3.3.1 MOX Fuel Fabrication Facility Licensing Schedule

For this analysis, it has been assumed that the duration of the NRC licensing process will be 5 years and that the process will start after the conceptual design is complete. (The licensing duration estimate is based on preliminary input from the NRC.) The NEPA process and the other site-specific permitting will require 3 years; each process will start after the site has been selected. The licensing schedule is shown in Table 2.15 and as a part of Sect. 2.3.6.

2.3.3.2 MOX Fuel Fabrication Facility Operation-Funded Project Cost

This section will cover LCC categories 1–6 in the 24-category estimating format described in Appendix C

Table 2.15. MOX fuel fabrication facility licensing and permitting schedule

Task name	Duration (months)	Start	Finish
Licensing and Permitting	60	12/1997	12/2002
NRC Licensing	60	12/1997	12/2002
Environmental/NEPA/DOE	36	12/1998	12/2001
Permitting	36	12/1998	12/2001

of this report. These six categories constitute what is termed *preoperational cost* or OPC in government accounting terms and include NEPA, compliance, licensing, and permitting. OPC is the portion of the TPC (investment, or up-front cost) budgeted with operating dollars rather than congressional line item capital or TEC dollars. Because this facility is likely to be government-owned and -funded, this distinction is important.

OPC generally includes the majority of the preconstruction activities and many of the startup activities carried on by the operating contractor before full capacity operation of the facility and after construction is complete. As seen in Table 2.16, NEPA, licensing, and permitting is just one of several needed cost centers.

R&D costs (category 1) represent early estimates of the R&D costs. It should be noted that the MOX fuel irradiation tests in a commercial reactor [lead-test assembly (LTA)] are covered under the reactor facility. The estimate of $35M for NEPA (post-1996 PEIS and new EIS activity), licensing, and permitting derives from the assumption that the licensing/ regulatory body, assumed to be NRC, will be reimbursed for the time required to process the license application. Conceptual design and the preparation of implementation plans (categories 3 and 4) are activities undertaken by the project office with the assistance of the DOE national laboratories and private contractors. (These costs do not include DOE salaries.) The startup activities funded (category 5) are those undertaken by the contractor that will operate the plant at eventual full production and do not include startup costs that are part of the construction contractor's mission. The startup costs are calculated by using a multiplier (1.24) on the projected average annual staffing cost (category 13) of $33M/year for the facility once it begins normal operations (Sect. 2.3.4.4). The costs in categories 1–5 have some contingency imbedded in each; however, allowances for risk created by significant schedule delays or the need for redesign are not included.

The total preoperational estimate of $100M is similar to normal vendor estimates, and in this cost model the OPC does not vary with the production capacity of the plant.

Table 2.16. Projected preoperational LCCs for the MOX fuel fabrication facility

Category	Cost category description	Lump-sum cost (1996 $M)
1	R&D	21
2	NEPA, licensing, and permitting	35
3	Conceptual design	2
4	Implementation plans for S&S, QA, and site qualification	1
5	Postconstruction startup	41
6	Contingency to cover cost/schedule risk	0
Total preoperational cost		$100

2.3.4 MOX Fuel Fabrication Facility Operations

2.3.4.1 MOX Fuel Fabrication Facility Shipment and Storage

After the plutonium is converted to PuO_2 at the PuP facility, the PuO_2 will be repackaged (using the packages described in Appendix G) and shipped to the MOX fuel fabrication facility. This facility will operate on a schedule similar to the existing LWR operation schedule (~10 years). This schedule may require that some of the PuO_2 be placed in a lead storage vault. The lead storage vault could be accommodated in the design of the MOX fuel fabrication facility design or by excess vault capacity at another DOE site.

Table 2.17 summarizes estimates of the number of packages and shipments required for this shipment leg. Shipment will be by SST. Each SST will transport between 28 and 35 packages with approximately three SSTs per convoy.

2.3.4.2 MOX Fuel Fabrication Facility Operations Process

The MOX fuel fabrication facility contains nine material processing and handling sections as shown in Fig. 2.9.

Table 2.17. Parameters for PuO_2 transport leg

Maximum plutonium/package (kg)	Quantity of plutonium/campaign (kg)	Estimated number of packages to be shipped	Number of SST shipments/campaign
4.5	50,000	31,000[a]	1,100

[a]The quantity of material included in each package will vary. The estimated number of shipments is based on an average shipment weight.

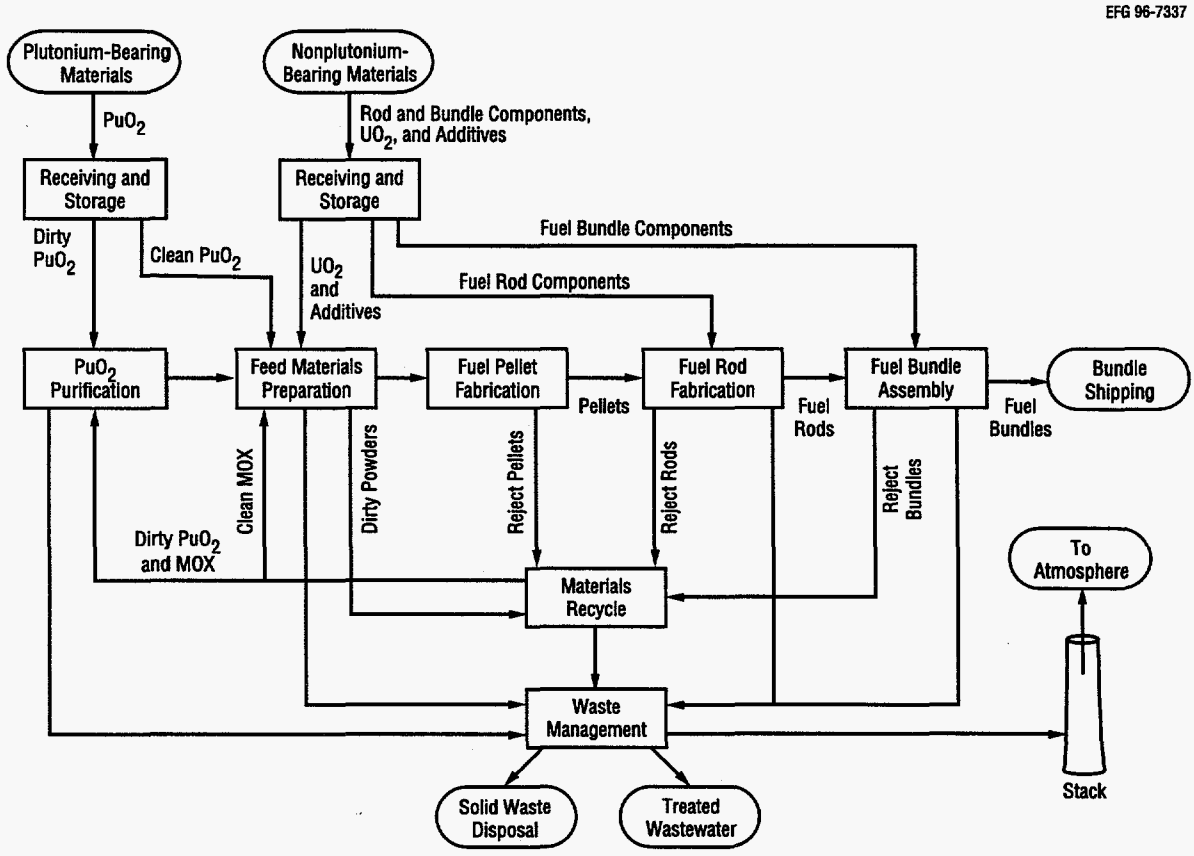

Figure 2.9. Generic MOX fuel fabrication facility process diagram

Receiving and Storage—In the materials receiving and storage area, all fuel fabrication components will be received, inspected, and sampled. After accountability is established, the materials will be stored while criticality controls on plutonium and surrounding materials will be observed.

The interim storage vault will receive PuO_2 that accumulates because of the higher throughput levels of the PuP facility compared with the MOX fuel fabrication facility. This vault will have a maximum capacity of 15 MT of PuO_2.

PuO_2 Purification—In this process, PuO_2 will be purified to the specifications for production of MOX fuel rods required for the reactors. The PuO_2 powder will be analyzed for contamination and, if it meets purity requirements, will go to PuO_2 storage without further processing. PuO_2 that does not meet the purity requirements will be dissolved, and the plutonium solution will be processed through an ion exchange process to separate the plutonium from impurities. It will then be treated to precipitate the plutonium, filtered, and calcined to PuO_2 powder. After analysis, PuO_2 meeting purity requirements will be sent to PuO_2 storage. PuO_2 that still does not meet purity requirements will be recycled through the purification process.

It is assumed that ARIES and other processes in the PuP facility will produce a PuO_2 product that is acceptable for MOX fuel fabrication without additional processing. Similarly, the material leaving the mixed-feed processing lines in the PuP facility will also meet the PuO_2 feed specifications. Consequently, the PuO_2 purification process step may be sized strictly to handle recycle material.

Feed Materials Preparation—PuO_2 from receiving and storage, the PuO_2 purification process, and/or the materials recycle process will be milled and screened to specification in batch lots. Any PuO_2 that does not meet dimensional specifications will be recycled through milling. Any PuO_2 powder that does not meet purity specifications will be sent to the materials recycle process. Several lots will then be blended to ensure consistency through extended periods of production. The PuO_2 will then be stored until needed. UO_2 received from off-site in ready-to-use condition will be stored for later use. As needed, UO_2, PuO_2, and recycled MOX will be removed from storage and placed in feed bins. Each quantity will be weighed in correct proportion to form a batch and placed in a mill/blender to achieve homogeneity. Portions from several batches will be separated and cross-blended, then reblended by being passed through the mill/blender again to form a large lot. The powder will be agglomerated to form a free-flowing press feed and placed in storage. Batch size will be determined by criticality safety limits on mass, but uniformity over much larger process units is desired to minimize sampling and optimize product consistency. All operations (including those that are automated) will be performed in gloveboxes.

Fuel Pellet Fabrication—Conditioned feed material from either the storage or feed materials preparation process will be pressed into pellets, loaded into sintering boats, and then stored until needed. Rejected pellets will be sent to material recycle. After the boats are placed in the sintering furnace, they will be sintered in an atmosphere of argon (or nitrogen) with low levels of hydrogen. The pellets will then be removed from the furnace and held in storage until needed. Rejected pellets will be sent to material recycle. Sintered pellets will then be ground to dimension and inspected for dimensional conformance, purity, and fissile content. Again, unacceptable pellets will be sent to the material recycle process. Acceptable pellets will be placed in storage until needed. All pellet operations except sintering will be performed in gloveboxes.

Fuel Rod Fabrication—Fuel rod fabrication will begin with preparing rods for loading with fuel pellets. Stacks of pellets, springs, and spacers will be assembled and loaded into the rods. The open end of the rod will be decontaminated, and the end cap welded. The rod will be inspected for dimensional tolerance and fissile loading and a leak test performed. Defective rods will be recycled. Acceptable rods will be cleaned and stored pending assembly into fuel bundles.

Fuel Bundle Assembly—This process will prepare the components for fuel bundle assembly and remove the fuel rods from storage. The bundle will be assembled, cleaned, and inspected for dimensional conformance. The bundle will be then stored pending transfer to a reactor. Rejected bundles will be sent to the materials recycle process.

Materials Recycle—When possible, materials will be recycled to reduce amounts going to the on-site waste management facility.

Waste Management—Wastes will be sent to the on-site waste management facility for processing and packaging before being sent to WIPP or a low-level waste (LLW) burial ground.

Bundle Shipping—Shipping the MOX fuel bundles to the existing LWR facilities is discussed in Sect. 2.4.4.1.

Table 2.18 lists the batch characteristics for the receiving and storage, fuel fabrication, and shipping processes.

2.3.4.3 MOX Fuel Fabrication Facility Operations Schedule

The preoperational checkout of the MOX fuel fabrication facility will start as soon as the construction is complete and will require 2 years. During the first 6 months of operation, the LUAs will be fabricated. Following this startup period, the MOX fuel fabrication facility will operate for 9.8 years with an annual plutonium throughput of 5.1 MT. This throughput will supply fuel for five large LWRs at the specified loading rate and assumes an annual output of 280 assemblies, for a mission total of 2756 assemblies. The operational schedule is shown in Table 2.19 and as a part of Sect. 2.3.6.

2.3.4.4 MOX Fuel Fabrication Facility Operations Costs

Operations costs for the MOX fuel fabrication facility constitute more than just the cost of staffing and consumables for the 9.8 years of MOX fuel fabrication

Table 2.18. MOX fuel fabrication facility batch process data

Process	Process cycle data[a]	Data (average)
Receiving and storage	Plutonium throughput Cycle time Plutonium input form Plutonium output form	423 kg 1 month PuO_2 PuO_2
MOX fuel fabrication	Plutonium throughput Cycle time Plutonium input form Plutonium output form	5080 kg 1 year PuO_2 MOX fuel bundles
Bundle shipping	Plutonium throughput Cycle time Plutonium input form Plutonium output form	280 bundles, 18.14 kg/per bundle 1 year MOX fuel bundles MOX fuel bundles

[a]Plutonium throughput represents amount of PuO_2 received in a single shipment. Cycle time represents interval between expected shipments of PuO_2.

Table 2.19. MOX fuel fabrication facility operational schedule

Task name	Duration (months)	Start	Finish
Preoperational Phase	24	12/2004	12/2006
PuP Facility Complete			9/2006
MOX Fuel Fabrication Facility Ready for PuO_2			12/2006
Operation	124	12/2006	4/2017
MOX Facility Operation Start			12/2006
LUA Fabrication	6	12/2006	6/2007
Operation	118	6/2007	4/2017

facility operations. Waste handling, fees, capital upgrades, transportation, and oversight also are included. These costs are reflected in categories 13–19 and item 23 of the 24-category format in Table 2.20. These costs are recurring costs, since the annual costs remain nearly constant over the plant lifetime for a given production rate (in this case 118 MTHM/year).

An approach developed by ORNL and LANL was used to calculate the sum of all recurring costs, not including transportation of PuO_2 powder to the MOX fuel fabrication facility from the PuP facility. The costs scale with throughput (MTHM/year) with the addition of a fixed component of $50M/year, which exists independent of the production rate up to 45 MTHM/year. (The cost of maintaining a plutonium handling facility is $50M/year, even without production.) The MOX fuel fabrication facility is assumed to use automated rather than hands-on technology, thus reducing the number of staff needed and reducing personnel radiation exposure. The model used is as follows:

Annual recurring cost (not including transportation) = $50M/year + 0.6 (MTHM/year – 45).

For the 118-MTHM/year production rate for the MOX fuel fabrication facility, a recurring cost total of $93.8M/year results. This cost is incurred for each of the 9.8 years of MOX production for a total of $920M. The short life of the facility (9.8 years) should significantly reduce the capital upgrade rate, that is, the fraction of TEC that represents the need to replace major equipment items that fail or wear out. The fact that an existing federal site is being used also results in shared indirect or overhead costs with other site functions, as opposed to a greenfield plant where all overhead would be assigned to the MOX fuel fabrication facility cost center. Such overhead functions include security, waste handling, and analytical laboratories. The annual cost calculated from the algorithm was partitioned into the 24-category format needed for the LCC analysis. Table 2.20 shows the result of this partitioning and the cost basis for most entries. A few assumptions should be noted regarding some of the entries:

Table 2.20. Recurring and other LCCs for existing LWR MOX fuel fabrication facility base case in 24-category format

Category	Cost category description	118-MTHM/year government MOX plant in existing building	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 9.8		
	Staff size (total): FTEs @ $77,900/year/FTE: 426 FTEs		
	Staff size (directs): 110 FTEs		
	Staff size (indirects): 316 FTEs		
13	O&M staffing	324	33.1
14	Consumables (including utilities)	321	32.8
15	Major capital replacements or upgrades	170	17.3
16	Waste handling and disposal	68	6.9
17	Oversight	10	1.0
18	M&O contractor fees (2% of categories 13–16)	18	1.8
19	PILT to local governments (1% of categories 13–16)	9	0.9
	RECURRING COST SUM FROM PARTITIONING	$920	$93.8
20	D&D (20% of TEC)	60	
21	Revenues (if applicable) from sale of MOX or electricity	–1387	–141.5
22a	Revenue from sale of reactor	N/A	
22b	Fees to privately-owned facility	0	
23	Transportation of plutonium forms to facility (OR T&PT)	26	2.7
24	Storage of plutonium at existing 94-1 site facility	N/A	
	TOTAL OTHER LCC	–$381	–$45.0[a]

[a]Total recurring cost before MOX revenue is $96.5M/year.

O&M Staffing (category 13)— The MOX fuel fabrication facility is projected to need 110 direct and 316 indirect FTEs for a total of 426 employees. Staff costs are based on a weighted average loaded salary of $77,900/year, which represents $70,000/year for directs (operators/mechanics/technicians on the plant floor) and $80,000/year for each indirect or overhead person, including plant management. The high ratio of indirects to directs (more than 3) is typical of plutonium-handling facilities and reflects the stringent ES&H, regulatory, and QA requirements for operation of such facilities.

Major Capital Replacements (category 15) —The capital replacement rate is based on ~6% of TEC per year. For a MOX facility with a longer operating life, this percentage could be higher due to increased equipment wear.

Waste Handling (category 16)—Annual waste disposal costs of $6.9M/year include the disposal of TRU waste and LLWs. The TRU waste disposal cost is based on 590 bbl of waste per year sent to WIPP at a cost of $10,000/bbl. LLW disposal costs are based on 4730 ft^3/year of waste at a disposal fee of $200/$ft^3$. This MOX cost partitioning model assumes that waste disposal costs scale with throughput. Compared with the other LWR alternatives, this MOX fuel fabrication facility has the highest waste disposal cost because it has the highest throughput (118 MTHM/year).

Oversight (category 17)—The analysis assumes that NRC oversight and inspections will be paid for by DOE. An annual cost of $1M/year is projected for this purpose.

M&O Contractor Fees (category 18)—M&O contractor and in-lieu-of-tax payments are calculated as fixed percentages (2% and 1% respectively) of the total of categories 13–16.

MOX Sales Revenues (category 21)—The analysis assumes that the PWR reactor utility owners will not need to buy 9.8 years worth of LEU fuel as a result of the MOX fuel campaign. Assuming that 1 kg of MOX fuel produces the same amount of energy as 1 kg of LEU fuel, 1163 MT of LEU fuel are assumed to be displaced. Because the incentive to the utility is an irradiation fee (discussed in Sect. 2.4.4.4) rather than free fuel, DOE–FMDP is assumed to receive MOX fuel sales revenues from the utility at the LEU fuel-equivalent price of $1193/kg of heavy metal (HM) based on the following costs for commercial fuel cycle service and materials for production of LEU fuel:

Uranium ore:	$15/lb U_3O_8
Conversion (U_3O_8 to UF_6):	$6/kg U
Enrichment (4.2% ^{235}U product assay and 0.3% ^{235}U tails assay):	$100/SWU
Fabrication:	$200/kg HM

This revenue is multiplied by the total LEU fuel displaced to obtain a total life cycle revenue of $1.387B. It should be noted that market price variation in the fuel cycle materials and services can place the unit LEU fuel cost in the range of $900–1500/kg HM. (In DOE's TSR document, this category is called the "fuel displacement credit.")

Transportation (category 23)—The annual transportation cost of $2.7M/year includes transportation of PuO_2 powder from the existing SRS PuP facility to the federal MOX fuel fabrication facility site and the transportation of wastes from the MOX fuel fabrication facility to their final disposal site.

Summing the partitioned recurring and transportation costs gives a total of $96.5M/year for the MOX fuel fabrication facility not including MOX fuel sales revenue.

The recurring costs ($920M) plus transportation ($26M) sum to $946M. Addition of D&D costs ($60M) increases the "other LCC" total to $1006M before any MOX sales revenues. Subtracting the $1387M in revenues yields a net cash flow of –$381M.

2.3.5 MOX Fuel Fabrication Facility D&D

The MOX fuel fabrication facility will be constructed for the sole purpose of dispositioning surplus plutonium identified by this program. At the completion of this mission the MOX fuel fabrication facility will be promptly decontaminated and decommissioned.

2.3.5.1 MOX Fuel Fabrication Facility D&D Schedule

The duration for D&D of the facility is estimated to be 2 years (Table 2.21).

Table 2.21. MOX fuel fabrication facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP ROD			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Fuel Qualification Demonstration	60	4/1996	4/2001
Site and Facility Selection	12	12/1997	12/1998
Select M&O Contractor	12	12/1998	12/1999
Licensing and Permitting	60	12/1997	12/2002
Design Process	60	12/1996	12/2001
Facility Modification	36	12/2001	12/2004
Preoperational Phase	24	12/2004	12/2006
PuP Facility Complete			9/2006
MOX Fuel Fabrication Facility Ready for PuO_2			12/2006
LUA Fabrication	6	12/2006	6/2007
Operation	118	6/2007	4/2017
D&D	24	4/2017	4/2019

2.3.5.2 MOX Fuel Fabrication Facility D&D Costs

The analysis assumes that the MOX fuel fabrication facility will not be used for commercial MOX fuel fabrication at the end of the excess plutonium disposition mission but will undergo D&D. The goal of D&D is not to return the area to a greenfield state but to remove and dispose of contaminated equipment and to return the building to habitable status. At this stage of cost estimating, D&D is usually calculated as a percentage of TEC. A value of 20% is used here because the TEC is low compared with a greenfield facility, and FMDP will be required to return a clean building to site management at the end of the facility's life. Therefore, 20% of $300M provides $60M for D&D (category 20) as shown on Table 2.20.

2.3.6 MOX Fuel Fabrication Facility Schedule Summary

The overall MOX fuel fabrication facility implementation schedule is summarized in Table 2.21 and shown in Fig. 2.10. This facility schedule is also shown in the discussion of the complete alternative schedule in Sect. 2.6.1. This schedule does not include any contingency for schedule delays caused by site selection difficulties, redesign, construction delays, or a delay in the approval of line item funding.

The critical path through development of this facility is through the conceptual design and the NRC licensing process before construction may begin. If either of these tasks slips in its schedule, the rest of the implementation process will also be delayed. This critical path is shown in Fig. 2.10.

2.3.7 MOX Fuel Fabrication Facility Cost Summary

Table 2.22 shows a summary of the MOX fuel fabrication facility LCCs in the 24-category format. All anticipated MOX fuel fabrication facility-related costs from FY 1997 forward are included in this table. The total MOX-related costs before revenues sum to $1406M. After adjustment for the $1387M in revenues, the net LCC is only $19M.

2.3.8 MOX Fuel Fabrication Facility S&S Summary

As discussed in Sect. 2.2.8, DOE and its predecessor agencies have successfully managed safeguards and security of SNMs for several decades.

This section discusses the vulnerabilities to theft and unauthorized access intrinsic to the material forms and processing environments in the MOX fuel fabrication

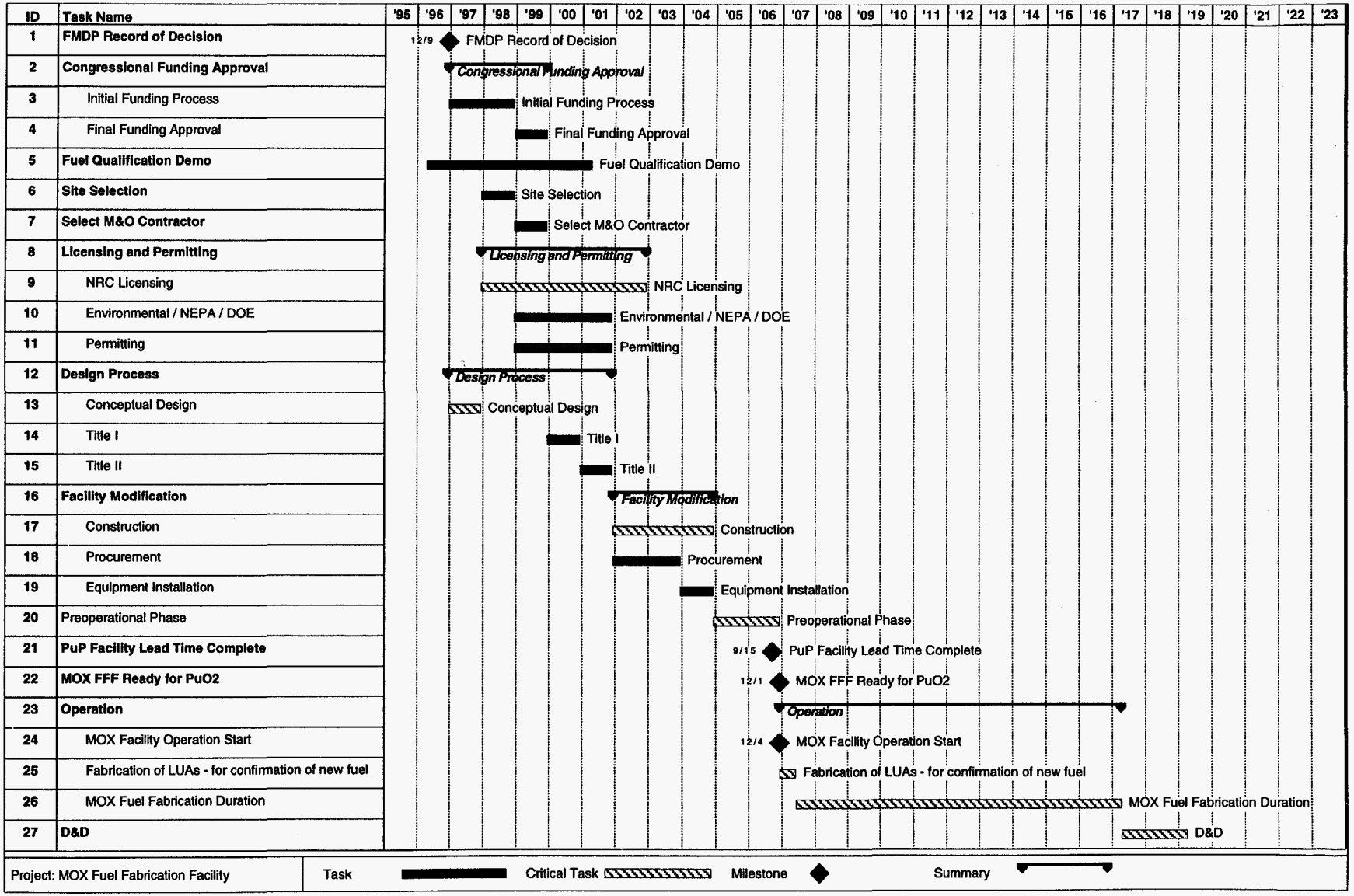

Figure 2.10. MOX fuel fabrication facility schedule summary

Table 2.22. LCCs for five-PWR MOX fuel fabrication facility in 24-category format

Category	Cost category description	118-MTHM/year government MOX plant in existing building	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 9.8		
	Preoperational or OPC part of up-front cost		
	Up-front costs:		
1	R&D	21	
2	NEPA, licensing, and permitting	35	
3	Conceptual design	2	
4	Implementation plans: QA, site qualification, S&S plans	1	
5	Postconstruction startup	41	
6	Risk contingency	0	
	TOTAL OPC	$100	
	Capital or TEC part of up-front cost		
7	Title I, II, III engineering, design, and inspection	48	
8a	Capital equipment	150	
8b	Direct and indirect construction/modification	51	
9	Construction management (in categories 8a and 8b)	0	
10	Initial spares	12	
11	AFI (15% of categories 7–10)	39	
12	Risk contingency	0	
	TOTAL TEC	$300	
	TOTAL UP-FRONT COST(TPC)	$400	
	Other LCCs		
	Staff size (total): FTEs @ $77,900/year/FTE: 426 FTEs		
	Staff size (directs): 110 FTEs		
	Staff size (indirects): 316 FTEs		
13	O&M staffing	324	33.1
14	Consumables (including utilities)	321	32.8
15	Major capital replacements or upgrades	170	17.3
16	Waste handling and disposal	68	6.9
17	Oversight	10	1.0
18	M&O contractor fees (2% of categories 13–16)	18	1.8
19	PILT to local governments (1% of categories 13–16)	9	0.9
	Recurring cost sum	920	93.8
20	D&D (20% of TEC)	60	
21	Revenues (if applicable) from MOX or electricity	−1387	−141.5
22a	Revenue from sale of reactor	N/A	
22b	Fees to privately owned facility	0	
23	Transportation of plutonium forms to facility	26	2.7
24	Storage of plutonium at existing 94-1 site facility	N/A	
	TOTAL OTHER LCC	−$381	−$45.0
	GRAND TOTAL NET LCC (1996 dollars)	$19[a]	

[a]MOX-related costs sum to $1406M before MOX sales revenues.

facility. In the sense employed here, a "risk" is a set of conditions that require specific measures to ensure proper physical control of SNMs. *These risks should not be interpreted as the overall risk to which the material will be subject in the as-built facilities.* The overall risk in the as-built facility is driven to very small values by the S&S measures incorporated in the design and operation of the facility.

Possible Diversion, Theft, or Proliferation Risks—For this facility, the material and concentration will still meet the definition for Category IC material even with changing form. However, with respect to both covert and overt theft, considerable differences will exist as the material is made into MOX fuel. Again, the facility operations will involve a large number of processing steps and handling bulk material, which is relatively accessible. The input material will be oxide powder, and the risk of covert and overt theft is greatest in the early process steps. As the plutonium oxide is blended with uranium oxide to make pellets, the concentration of the plutonium will decrease. Because these forms are accessible and transportable, they will still be attractive targets for both covert and overt theft, although more material would be needed to make a nuclear device. After the pellets are fabricated into fuel rods and subsequently into fuel assemblies they are much less transportable; thus, they become more difficult targets for overt theft. Likewise, the fissile material within the fuel rods and assemblies will no longer be physically accessible and will be accounted for using item accountancy, thereby reducing the opportunities for covert theft to a low risk and for overt theft to a medium risk.

Environmental Conditions—Table 2.23 provides processing environment conditions, material form, and other S&S information. The environment for the first part of the MOX fuel fabrication facility will be very similar to that of the PuP facility, and the intrinsic process risk will be at its highest. After fuel rods and assemblies are made the risk will be reduced. The facility will be a Category I facility with a high throughput and a nearly continuous operation. No intrasite transport will be required outside the MAA, and again SSTs will be used to both deliver and pick up the material.

Material Form—As in the case of the plutonium processing facility, the initial feed materials (e.g., oxide and unirradiated fuel) are very attractive materials (IC). The intrinsic attributes of this material will be the same as described previously. Once the material has been blended it would be slightly more difficult to convert to a weapons-usable form; and because the concentration of the plutonium will be lower, more material would be required to acquire a significant quantity. Once the MOX fuel is placed into fuel rods and then fuel assemblies, its chemical, isotopic, and radiological attributes would not change, but the mass/dimensions of the "containers" would increase, thus making it more difficult to move.

S&S Assurance—During the initial processing operations, until the material is placed into the fuel rods, bulk accountancy would be conducted and then item accountancy would be performed. Although devices are being developed to perform NDA on fuel rods/assemblies, NDA is still a very time-consuming activity. Once the material is placed inside the fuel rods it would no longer be accessible and would require special handling equipment to move the assemblies.

Potential Risks of Diversion—Opportunities for diversion in this facility for the initial process operations will be similar to those for the PuP facility. After the material has been blended, it will become a less attractive target. Once the material is made into fuel rods and assemblies and item accountancy is used, the possibility for diversion will be reduced and the risk will be medium. Because the fuel rods and assemblies will be quite large and require special handling equipment, containment and surveillance (C/S) measures can more easily detect diversion attempts.

Difficulty of Diversion, Retrieval, Extraction, and Reuse—The attractiveness of the material in the early processing steps will be similar to that during the plutonium processing activities and will be high. If diversion should occur, only moderate chemical barriers would exist to prevent conversion and reuse, and the risks would be medium. Once the material is blended, the concentration of plutonium will be decreased and its attractiveness will be reduced. Once the material is made into MOX fuel and placed into fuel rods and assemblies, the material will become more difficult to divert.

Assurance of Detection of Retrieval and Extraction—The front-end operations in this facility will be similar to those in the PuP facility. After the material has been blended, a greater quantity of material will be required to accumulate a significant quantity. Once it has been placed into fuel rods and assemblies, the individual items will be accounted for. This accounting will increase the ability to detect diversion; therefore, the risk will be only moderate.

Table 2.23. Nonproliferation and S&S risk assessment for the existing LWR base case MOX fuel fabrication facility

Environment								
Facility	**Activity**	**Duration**	**Throughput plutonium**	**Waste streams**	**Maximum plutonium inventory**	**Intrasite transport**	**Number of processing steps**	**Barriers**
MOX fuel fabrication facility			5.1 MT	Yes (1 g/L)	5.1 MT	No	5	MAA
	Receiving and storage	1 month	425 kg plutonium			No, SST unload	0	
	MOX fuel fabrication	1 year	5080 kg/batch 118 MTHM/year			No	5	Glovebox
	Fresh fuel shipping	1 year	280 assemblies 18.14 kg/plutonium assembly		5080 kg/ batch	No, SST load	0	
Transport	MOX fuel fabrication to reactor		28 SSTs per batch, 5 containers with 2 bundles each per SST					

Table 2.23. Nonproliferation and S&S risk assessment for the existing LWR base case MOX fuel fabrication facility (cont.)

Material form									
Facility	**Activity**	**SNM input**	**SNM output**	**Quantity of plutonium**	**Concentration of plutonium (other fissile materials)**	**SNM category***	**Radiation barrier**	**Chemical composition**	**Isotopics**
MOX fuel fabrication facility					No other fissile material	DUU			
	Receiving and storage	Oxide, MOX fuel unirradiated	Metal, oxide, MOX fuel			IC	No	Oxide	
	MOX fuel fabrication	Oxide	Fuel assemblies			IC	No	Oxide, pellets, rods, assemblies	0.94 ^{239}Pu
	Fresh fuel shipping	MOX fuel assemblies (fresh)	Fuel assemblies	18.14 kg per assembly	0.043 g/g HM	IC	No		
Transport	MOX fuel fabrication to reactor								

Note: DUU—direct use unirradiated.
*See Table 2.12.

Table 2.23. Nonproliferation and S&S risk assessment for the existing base case LWR MOX fuel fabrication facility (cont.)

S&S								
Facility	**Activity**	**Number of MBAs**	**Type accounting system**	**Nuclear measure**	**Classified material**	**Physically accessible**	**Access**	**Special handling equipment**
MOX fuel fabrication facility		~5	50% Item	0.6% (domestic) 2.5% (international)				
	Receiving and storage		Both bulk and item	Calorimetry, neutron, gamma	No	Yes	Hands-on	No
	MOX fuel fabrication		Bulk		No, proprietary	No	Hands-on, remote	No–Yes (for rods/ assemblies—crane)
	Fresh fuel shipping		Item		No	No		Yes (for assemblies—crane)
Transport	MOX fuel fabrication to reactor					Yes		

Note: MBA—material balance area.

2.3.9 MOX Fuel Fabrication Facility Technical Viability

As previously indicated, five factors were considered to develop a qualitative assessment of the technical viability of a concept. (A quantitative assessment of technical viability is presented in Appendix E.)

Technical Maturity—MOX fuel fabrication is a well-developed technology, considerably into the industrialization/commercialization stage, with commercial LWR MOX fuel plants currently operating in Great Britain [British Nuclear Fuels, Limited (BNFL)], France (COGEMA), and Belgium (Belgonucleaire). Most of the processes employed in these commercial operations will also be employed in the MOX fuel fabrication facility for plutonium disposition.

Variations from commercial technology will be required to meet the goals of the disposition program. These new/additional processes are at varying levels of technological development.

An important variation from commercial technology will be the use of weapons-grade plutonium isotopics instead of reactor-grade plutonium isotopics. However, this change will likely not influence the choice of technology, but only the engineering implementation of a technology (e.g., sizing of equipment).

Technical Risks—MOX fuel fabrication is a well-developed technology with a large amount of commercial experience in Europe. One technical issue that must be resolved is that the plutonium feed material will have impurities that are not present in plutonium that results from reprocessed LWR spent fuel.

Unacceptable fuel production will delay the disposition of plutonium and jeopardize achievement of program goals. Considering the current levels of technical development, the degree of risk associated with the MOX fuel fabrication process is thought to be low.

R&D Needs—Four R&D issues associated with MOX fuel fabrication will address each of these technology development needs.

1. Large-scale impurity removal—The R&D proposed is focused on developing impurity removal processes that would have minimal waste streams.
2. Feed plutonium impurity impact—As indicated before, the feed material of interest contains impurities that might adversely affect either fabrication or reactor operations. However, it is not certain that the effect of these impurities will be unacceptable, so R&D will be conducted to determine whether removal of impurities is unnecessary.
3. PuO_2 feed morphology—The powder blending stage of the fuel fabrication process is extremely sensitive to the morphology of the powder feeds. Because the feed material is coming from a variety of sources, it will be necessary to demonstrate that the morphology of the oxides can be altered to meet feed specifications.
4. Process scrap recovery—Technology currently exists for recovery and recycle of materials that fail to meet specifications at the various stages of fabrication. However, these processes are all aqueous-based processes and are significant waste generators. Several advanced processes have been proposed that would perform these operations with dramatically reduced waste streams; thus, R&D is proposed to develop these other alternatives.

2.4 Existing LWR Base-Case Variant Facility

The existing reactor facilities receive MOX fuel from the MOX fuel fabrication facility and irradiate it to achieve the characteristics defined in the FMDP SFS. These reactors will substitute MOX fuel for LEU fuel during the plutonium disposition mission.

2.4.1 Existing LWR Facility Description

Figure 2.1 shows that there are a number of PWR sites that are capable of completing the reactor portion of the plutonium disposition mission. These sites include nuclear steam supply systems furnished by B&W, Westinghouse, GE, and ABB-CE. For the typical mission times expected for this case, the use of B&W plants past 2017 (approximately) would require life extension. Life extension was not considered to be a part of the planning basis for this option.

Although in this base-case alternative a Westinghouse reactor was chosen as the surrogate reactor for all existing LWRs, it is *strongly* emphasized that this selection was not made on the basis of perceived technical superiority among the competing reactors

(e.g., no "down selection" process was employed). This selection was made because of the similarity in size to the majority of large PWRs potentially available for plutonium disposition and the availability of data on Westinghouse reactors. Large, existing BWRs that do not need license extension to complete the plutonium disposition mission could also be used in this alternative.

Figure 2.11 is a photograph of a typical two-unit plant site. The average plutonium throughput for all five reactors is a total of 5 MT/year. A representative overall facility size is roughly 1500 acres for a two-reactor site, and therefore, approximately 3750 acres for all five reactors.

As shown in Fig. 2.12, the reactor facility has four major processing and handling steps: storage and handling of fresh MOX fuel, irradiation of MOX fuel in the reactors, storage of irradiated (spent) nuclear fuel in on-site water pools, and a provision for dry storage of spent fuel. After refueling, spent fuel will be stored in the pools to cool. Ideally, spent fuel will be removed from the spent fuel pools after a 10-year postirradiation period and transported directly to a geologic repository. However, because the geologic repository may be not ready in time to receive spent fuel, the reactor facility also includes a fourth process step whereby spent fuel would be removed from the pools and placed into on-site dry storage in specially designed canisters. Figure 2.13 shows a typical fuel flow path in a cutaway view of a typical PWR facility.

Figure 2.14 shows a typical large four-loop nuclear steam supply system for a Westinghouse reactor. The associated PWR pressure vessel and reactor internals are shown in Fig. 2.15.

2.4.2 Existing LWR Facility Modification

The large PWRs under consideration for this alternative can use MOX as fuel without significant modification. Consideration may be given to upgrading the reactor control rods to a new type currently being installed in some existing commercial PWRs and to using enriched boron in the primary coolant. The only plant infrastructure that will need modification because of the introduction of MOX fuel is the fuel storage facility, which will need to be modified to adequately safeguard the MOX fuel.

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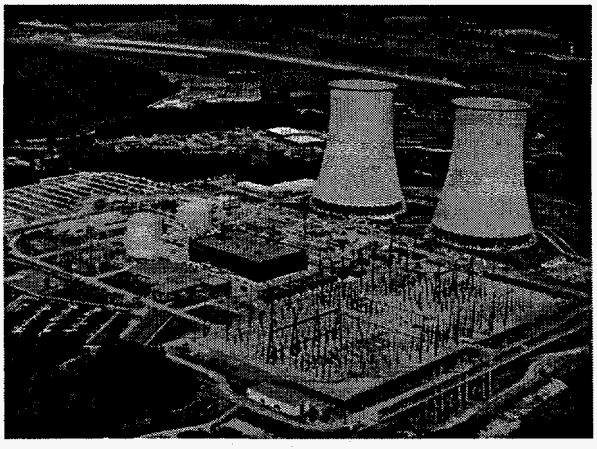

Figure 2.11. Typical two-unit PWR site

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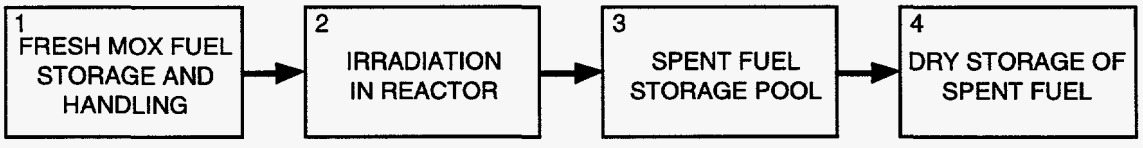


Figure 2.12. Existing LWR facility process diagram

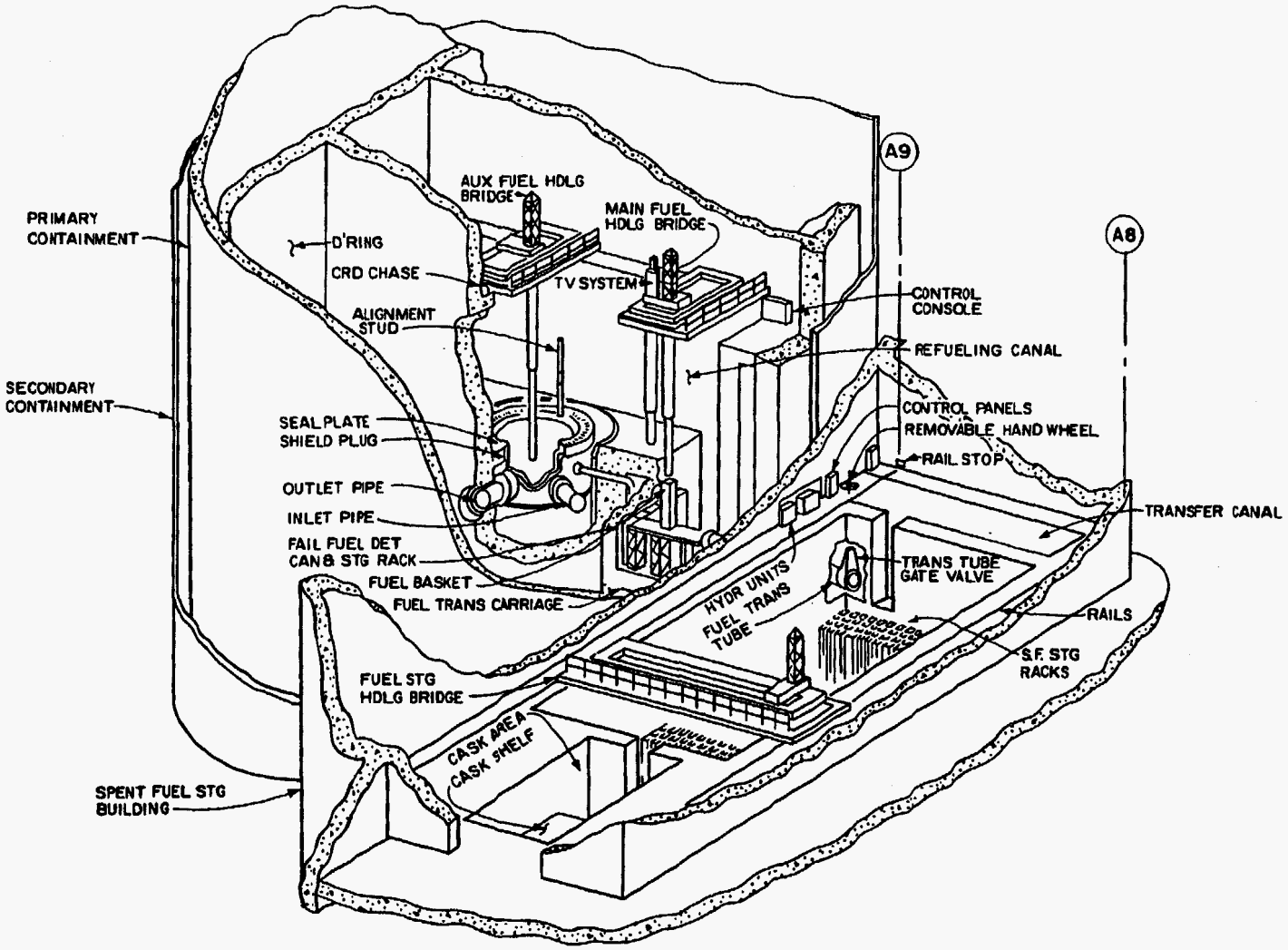


Figure 2.13. Typical PWR fuel transfer facilities

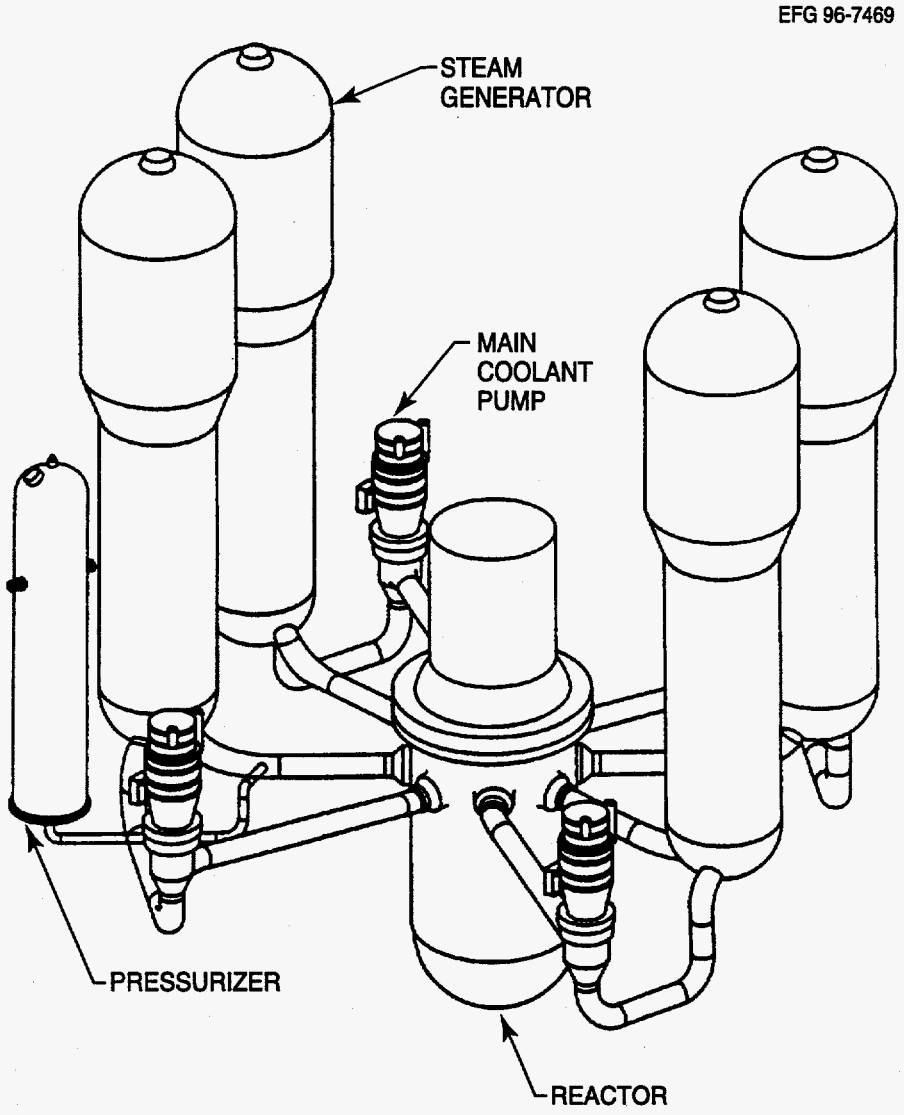


Figure 2.14. Typical Westinghouse four-loop PWR nuclear steam supply system

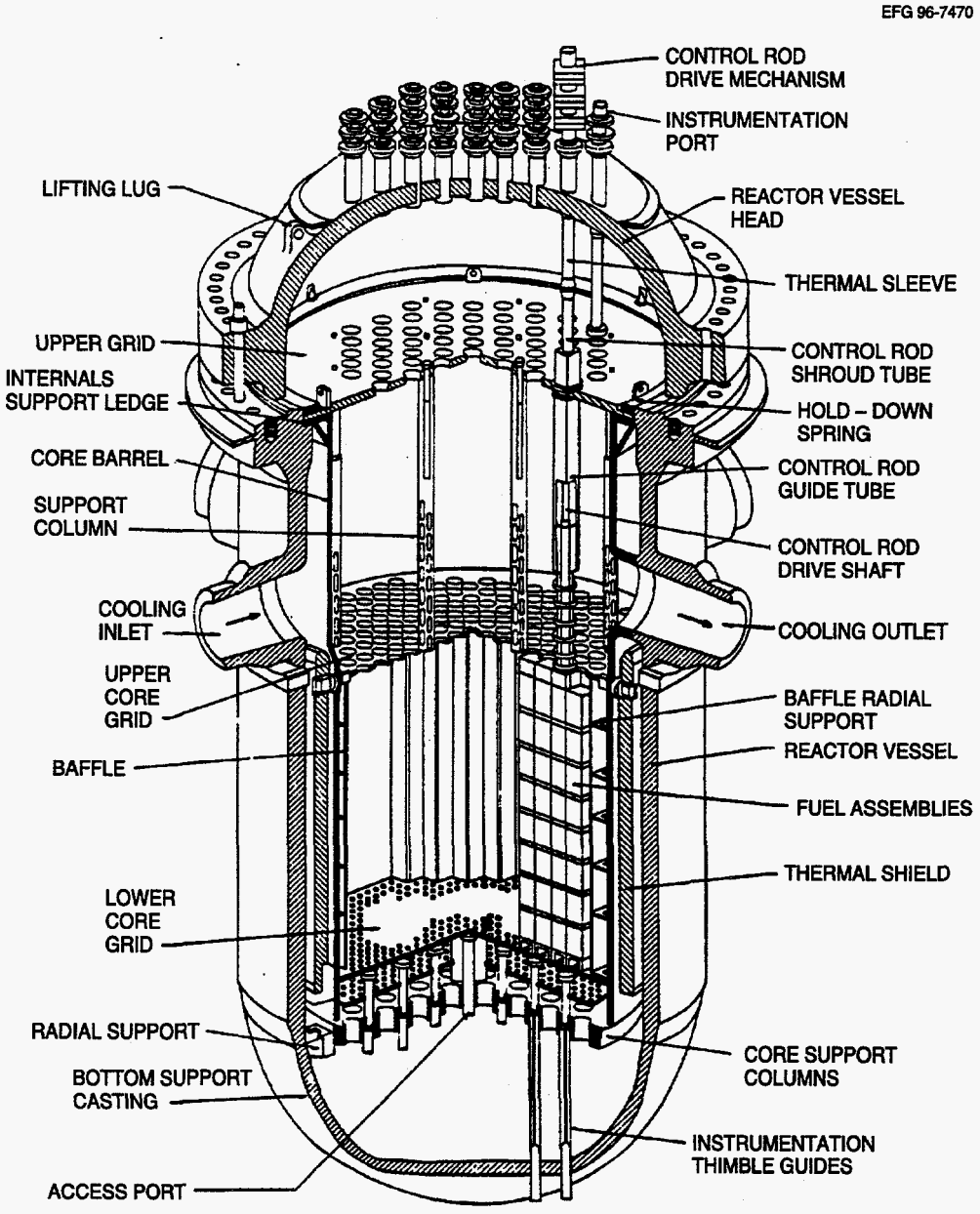


Figure 2.15. Typical Westinghouse reactor pressure vessel

2.4.2.1 Existing LWR Facility Design and Modification Schedule

After approval of line item funding, the project will begin with a year-long process to select the reactor utility or utilities. Reactor infrastructure modifications, which primarily consist of construction of a new fuel storage facility, are estimated to require 4 years. The design and construction schedule is listed in Table 2.24 and as a part of Sect. 2.4.6.

2.4.2.2 Existing LWR Facility Design and Modification Cost

The design and modification costs for the reactor facility are for modification of five Westinghouse PWRs to utilize MOX fuel. Most of the data in Table 2.25 are derived by interpolation from the three-reactor reference case and the six-reactor alternative case in Westinghouse's 1994 DOE-NE Phase II PDS report. The actual modifications to the PWRs, mostly in the area of control rod component replacement, will be straightforward and will not require additional outage time over normal LEU operations; hence, no replacement power need be purchased during the modification process. The engineering required for the modification process is estimated to cost $10M (including safety analyses), and the actual modifications and new buildings (MOX fuel storage vault and classified document vault) are estimated to cost $58M. These costs do not include the initial MOX core, which is covered under the MOX fuel facility. Management and spare parts are imbedded in category 8 and are not broken out. It is assumed that the reactor areas already have a perimeter security fence similar to the PIDAS fence that must surround the PuP facility and MOX fuel fabrication facility processing buildings. Contingency (AFI and risk contingency) has been included within each of the categories rather than as a separate item.

Table 2.24. Existing LWR facility design and modification schedule

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Intermediate Line Item Funding Approval	24	12/1996	12/1998
Utility Selection	12	12/1998	12/1999
Reactor Modifications	48	12/1999	12/2003

Table 2.25. Design and modification costs for five-LWR reactor facility

Category	Cost category description	Cost for five existing reactors (1996 $M)
	Capital or TEC front-end costs	
7	Title I, II, III engineering, design, & inspection	10
8a	Capital equipment (included in category 8b)	
8b	Direct & indirect construction/modification	58
9	Construction management (included in category 8b)	
10	Initial spares	None
11	AFI (included in category 8b)	
12	Risk contingency (included in category 8b)	
	TOTAL TEC	$68

2.4.3 Existing LWR Facility Licensing and Permitting

2.4.3.1 Existing LWR Facility Licensing and Permitting Approach

A clear path forward is provided in the existing licensing regulations promulgated by the NRC in regard to nuclear safety and radioactive waste management at commercial nuclear reactor facilities. The nuclear safety case for existing commercial LWRs has been reviewed by the NRC for operations on the uranium fuel cycle, and the owner/operators of LWRs will have been issued the complement of NRC materials possession and utilization facility operating licenses under 10 CFR Parts 30, 40, 50, and 70. In addition, all site permits under applicable federal environmental statutes should be current. Thus, the implementation of plutonium disposition in an existing LWR will be treated as a regulated change to existing licensing or permitting conditions.

A clear path forward is provided in the existing licensing regulations promulgated by the NRC in regard to nuclear safety and radioactive waste management at commercial nuclear reactor facilities.

The licensing approach for the reactor-based plutonium disposition options is to satisfy the NAS ES&H criteria "that any disposition option to operate in the United States

- should comply with NRC regulations governing allowable emissions of radioactivity to the environment, and allowable radiation doses to workers and the public, from civilian nuclear-energy activities;
- should comply with international agreements and standards covering the disposition of radioactive materials in the environment; and
- should not add significantly to the ES&H burdens that would be expected to arise, in the absence of weapons-usable plutonium disposition, from appropriate management of the environmental legacy of past nuclear-weapons production and from appropriate management of the ES&H aspects of past and future nuclear-energy generation."[1]

NEPA—License modification for use of MOX fuel in an operating commercial reactor can be done without issuing an EIS or an environmental assessment (EA) by means of a categorical exclusion, given that the provisions of 10 CFR 51.22(c)(9) are satisfied and that the NRC does not make a discretionary determination otherwise under 10 CFR 51.20(a)(2), 51.20(b)(14), and 51.22(b). Similarly, under 10 CFR 1021.400(c), although a major federal action is involved, use of an existing licensed and permitted facility with a published EIS in the public record would not trigger consideration for additional NEPA action by DOE if the conditions specified in Appendix B to Subpart D of 10 CFR Part 1021 are satisfied.

Atomic Energy Act of 1954, as amended—Amending or converting a license issued for a reactor under 10 CFR Part 50 is subject to the assessment and determination by NRC of "no significant hazards" considerations under 10 CFR 50.92(c), but this is not expected to be a significant issue for the fuel designs currently under consideration in the plutonium disposition program. U.S. precedents exist for MOX fuel test assemblies, and partial MOX cores are licensed and in operation in European LWRs with designs similar to those of U.S. LWRs. License modifications will be performed under the requirements of 10 CFR 50.90, 50.91, and 50.92. Such modifications will involve revising and obtaining NRC approvals for changes in the technical specifications under 10 CFR 50.36 and updating the licensing basis in the safety analysis report as required under 10 CFR 50.71(e). The minimum change expected in the technical specifications is the description of the reactor core as given in the "design features" section required under 10 CFR 50.36(c)(4). The licensee submits a safety analysis report with the application for amendment. Some portion of the changes in the plant design necessitated by the change to MOX fuel may not involve changes to the technical specifications or an unreviewed safety question as defined in 10 CFR 50.59(a)(2). Such changes will be documented and reported to the NRC as required under 10 CFR 50.59(b)(2) and 10 CFR 50.71(e).

RCRA—*Plutonium disposition represents no new or special permitting situation with regard to compliance with RCRA for treatment or disposal of hazardous waste.* For existing LWRs, RCRA permits will be in place, and the conditions of the permit should not change solely because of the change to MOX fuel in reload cores. However, because the plutonium disposition mission is a DOE program, all facets of it are

subject to the waste minimization/pollution prevention policies of the President and the Secretary of Energy in regard to the plans required of waste generators under Sect. 3002(b) of RCRA. Such a plan will be developed and implemented in cooperation with the owner or operator of the LWR consistent with EPA guidelines published in the *Federal Register.*

Clean Air Act and Clean Water Act—*No new permits are anticipated to be needed, and no new or unusual permitting situations or special requirements are anticipated to be applicable.*

2.4.3.2 Existing LWR Facility Licensing and Permitting Schedule

For this analysis, a schedule for modifying an existing LWR facility license to permit the use of MOX fuel without integral neutron absorbers was followed. The process to obtain a reload permit for a new fuel fabricator is also included in the permit schedule. The license and permit schedule is shown in Table 2.26 and Fig. 2.16.

After the reactor utility or utilities have been selected, the license amendment process is started with the preparation of the safety analysis report (SAR), the license amendment (LA) application, and the environmental report (ER). The NRC issues the safety evaluation report (SER) and the EA after completing the review of the application. The amended license is issued after the reactor facility modifications are complete. In addition, a reload license process is followed because of the use of a new MOX fuel. This analysis assumes that a 3-year lead use assembly (LUA) license process is followed before the LUAs are inserted into the reactor. After the LUAs have been irradiated for one cycle, 1.5 years in this case, a review of the LUA performance is completed. The reload permit for use of MOX fuel is granted after this review.

Table 2.26. Existing LWR facility license and permit schedule

Task name	Duration (months)	Start	Finish
NRC Interactions	51	12/1999	2/2004
Licensee Prepares SAR and License Amendment	12	12/1999	12/2000
Licensee Files Application			12/2000
Public Notice of Application for License Amendment	3	12/2000	3/2001
NRC Review	9	3/2001	11/2001
NRC Issues SER			11/2001
NRC Issues License Amendment	3	12/2003	2/2004
Notice of Amendment to Operating License			2/2004
Environmental/NEPA/NRC	24	12/1999	11/2001
Licensee Develops and Prepares ER	6	12/1999	6/2000
Licensee Files Report with NRC			12/2000
NRC Prepares and Issues Draft EA	6	12/2000	6/2001
NRC Issues Final EA	3	9/2001	12/2001
LUA and Reload Licenses	126	12/1999	5/2010
LUA Licensing	36	12/1999	12/2002
Reload Approval	18	12/2008	5/2010
Reactor Modifications	48	12/1999	12/2003
Fuel Qualification—LUAs	54	6/2007	12/2011
LUA Arrives			6/2007
LUA Irradiation	54	6/2007	12/2011

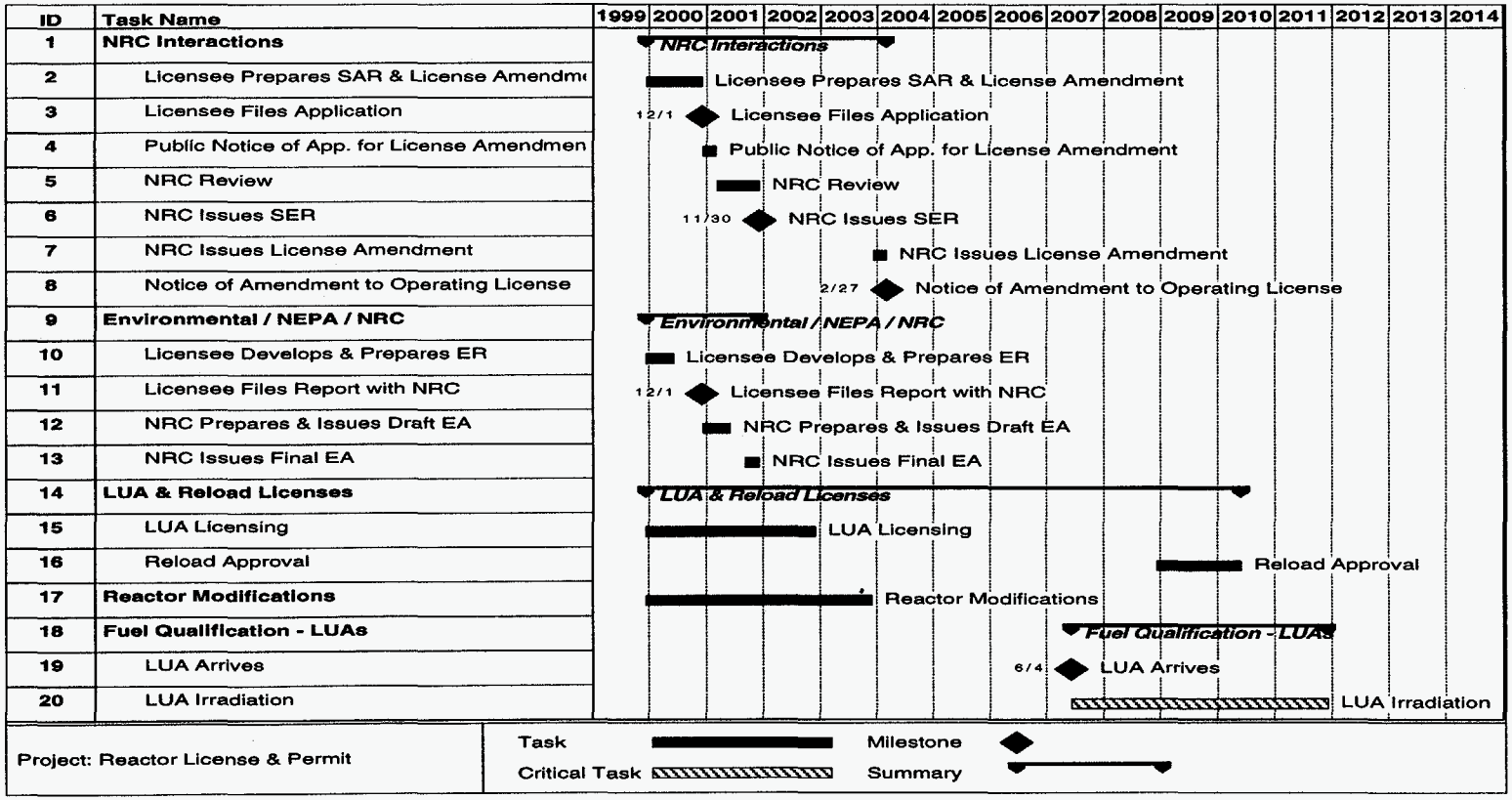


Figure 2.16. Existing LWR facility license and permit schedule

2.4.3.3 Existing Facility Operations-Funded Project Costs

Table 2.27 shows the preoperational costs for the five-LWR base case, which total $164M. Of this, $36M is for R&D (based on the 1995 Long Range RD&D Plan). The $103M for licensing and permitting (category 2) includes NRC licensing; the site-specific EIS; the licensing of the fuel transport package; and other state, federal, and local permits. The licensing cost includes reimbursement of the NRC's costs plus any licensing support work done by the utility or the national laboratories. Conceptual design and preparation of implementation plans (categories 3 and 4) is projected to total $3M. The cost of commissioning the five LWRs on MOX fuel is projected at $22M and includes MOX fuel shipping containers. No risk contingency was added to the modification program preoperational estimate.

2.4.4 Existing LWR Facility Operations

2.4.4.1 Existing LWR Facility Shipments and Storage

A total of 2756 LWR MOX fuel assemblies will be fabricated from the 50 MT of plutonium. The MOX fuel assemblies will be shipped from the MOX fuel fabrication facility to the existing LWR facilities (assumed for analysis purposes to be PWRs located in the midwestern United States). The MOX fuel fabrication facility, in providing fuel bundles for each reactor reload, must have the capacity to store completed fuel assemblies at the MOX fuel fabrication facility until they are needed. In addition, each reactor provides sufficient capacity for a cycle reload. Table 2.28 provides estimates of the number of shipments required to transport the fresh MOX fuel from the fuel fabrication facility to the existing LWR facility.

2.4.4.2 Existing LWR Facility Operations Process

Fresh MOX Fuel Storage Vault—The MOX fuel storage complex planning basis for this alternative is a single stand-alone ex-reactor building complex at the reactor site. This site is to be used for temporary storage of both new fuel and spent fuel. In this manner, the increased security associated with fresh MOX fuel would be limited to this complex until the fuel is transferred to the reactor building refueling floor just before the refueling operation starts. Security for the storage complex, the conceptual layout of which is shown in Fig. 2.17, would be provided by a double fence with a hardened guard post, personnel

Table 2.27. Preoperational costs for five-LWR reactor facility including licensing/permitting costs

Category	Cost category description	Costs for five existing reactors (1996 $M)
	Preoperational or OPC up-front costs:	
1	R&D	36
2	NEPA, licensing, permitting	103
3	Conceptual design	1
4	QA, site qualification, S&S plans	2
5	Postconstruction startup	22
6	Risk contingency	0
	TOTAL OPC	$164

Table 2.28. Parameters for fresh MOX fuel transport leg

Maximum assemblies/package	Quantity of plutonium/campaign (MT)	Estimated number of packages to be shipped	Number of SST shipments/campaign
Two PWR assemblies	50	1378	1378

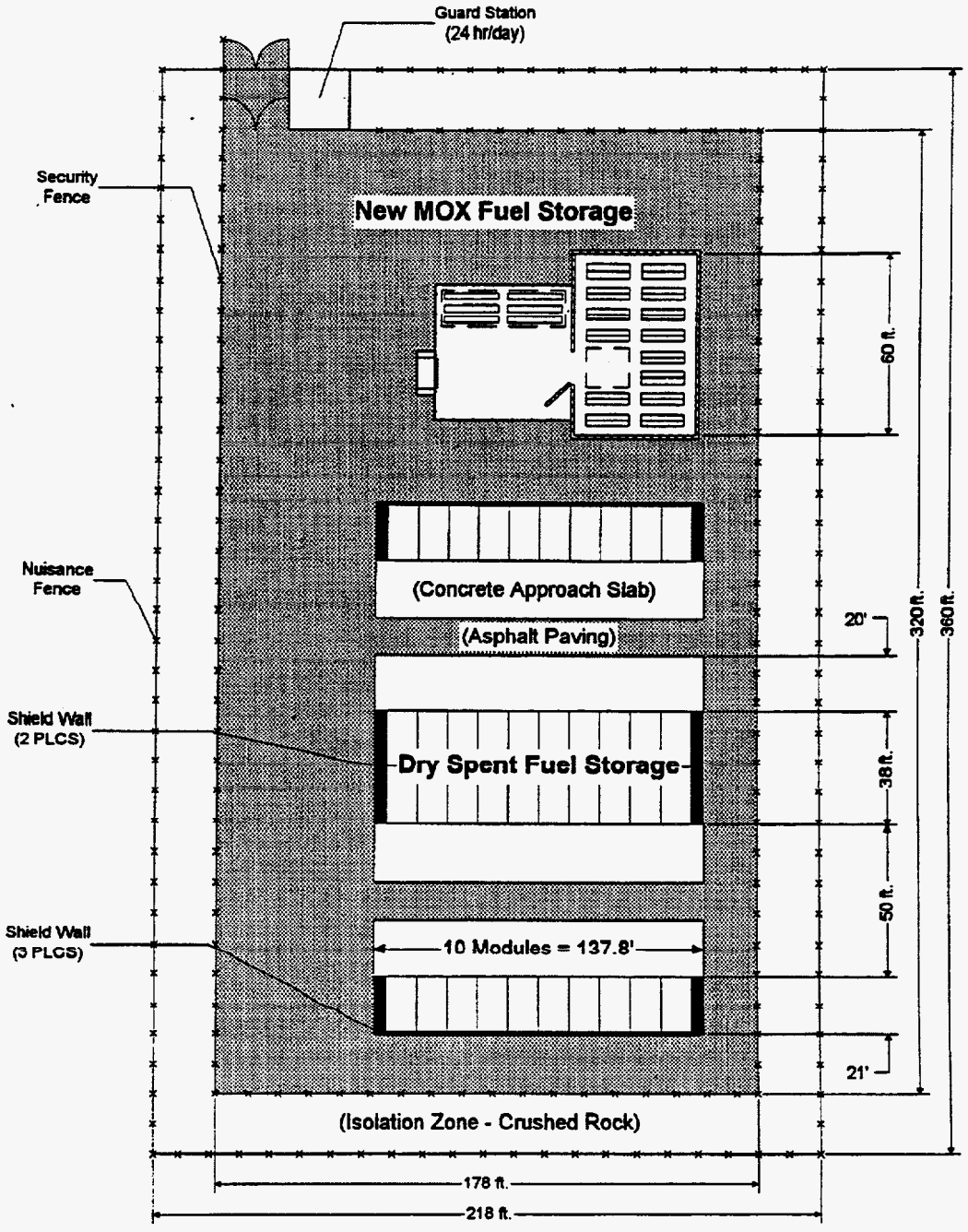


Figure 2.17. Security layout for the fresh MOX fuel storage vault

surveillance, access control, and communications. The new MOX-fuel storage vault portion of this proposed facility is shown in greater detail in Fig. 2.18. In reality, what was the fresh fuel storage for uranium fuel (it is recognized that the security plans greatly depend on the specific layout of the reactors chosen for the mission) would now be modified to accommodate MOX fuel. These modifications include the requisite security measures and MOX-specific fuel accountability considerations. The figures are shown for conceptual purposes.

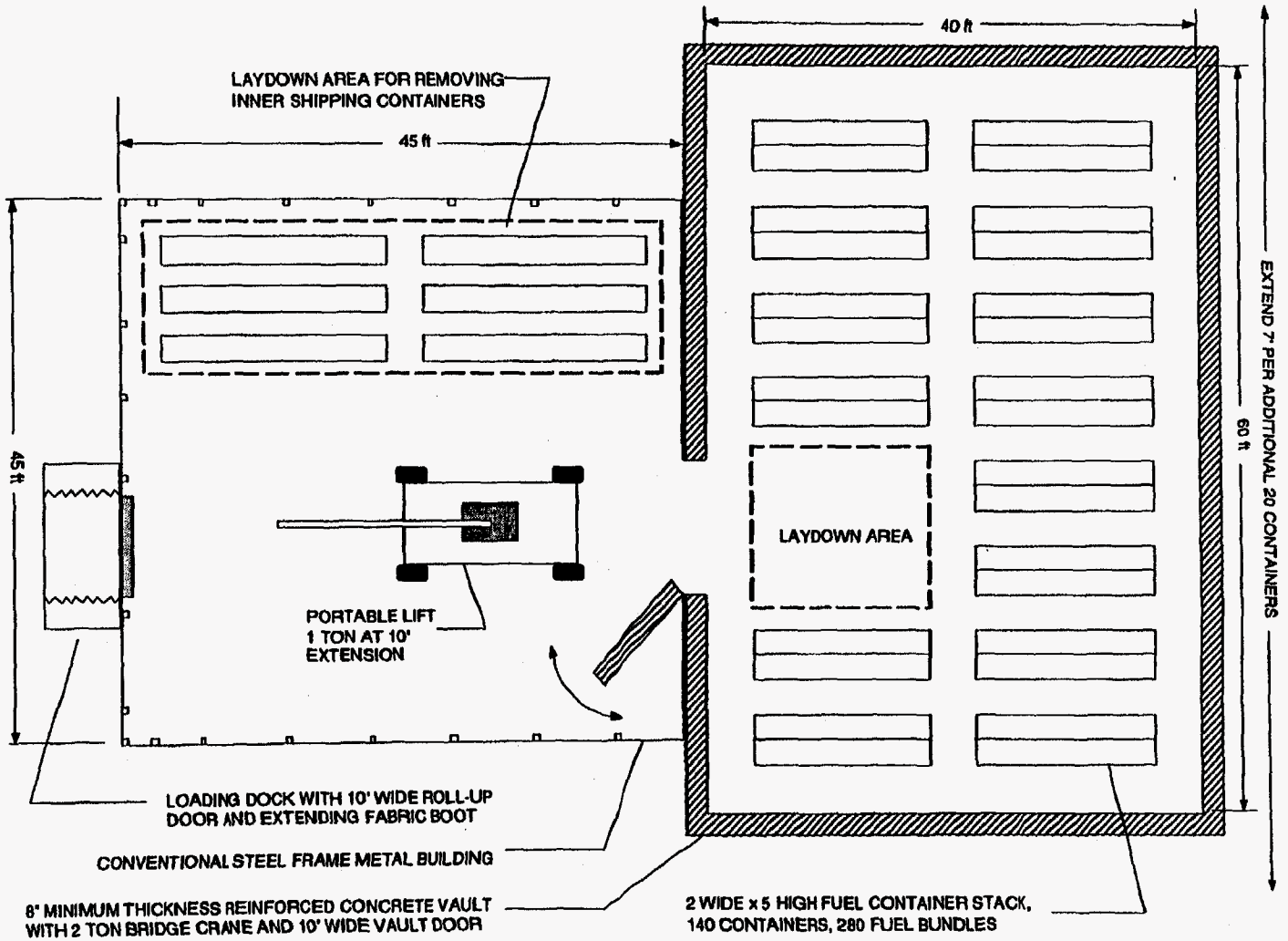


Figure 2.18. Fresh fuel storage vault layout

Fuel Storage Pool (Fresh Fuel)—Fuel shipping containers removed from the fuel storage vault would be lifted from the transport vehicle in the spent fuel storage building by the building crane. The shipping containers' TIDs will be verified and the container identification information recorded. The shipping containers will then be set upright and opened and the fuel bundles transferred to the cask loading area. Figure 2.13 illustrates the flow path once inside the reactor building.

The assembly will be transferred to a specified storage rack position in the pool for interim storage until core loading begins.

Irradiation in Reactor—Transfer of fuel from the fuel storage pool to the reactor core will be accomplished with the fuel transfer tube, as indicated in Fig. 2.13. The tube will be controlled from an operator station at each end of the tube.

The planning schedule calls for each MOX batch (84 assemblies) to remain in the reactor for a period of 4.5 years. Each batch will undergo irradiation for a total of approximately 1314 effective full-power days (EFPD). The average discharge exposure will be 45,000 megawatt days per metric ton of heavy metal (MWd/MTHM), similar to LEU fuel usage. (Some fuel shifting will occur within the core at the end of each cycle. In actuality, some fuel assemblies will remain in the reactor for two cycles, while others will be irradiated for three cycles. Optimization of the core design will be done if this alternative is chosen.

As noted in Appendix A, Sect. A.1, the reactor designs have not been optimized for this study. For scheduling and costing purposes, uniform batches of fuel with uniform irradiation cycles were assumed.

Another assumption made for this study was that 84 uniform MOX fuel bundles would be loaded at each fuel cycle, using no integral burnable poisons. In reality, some number of transition cycles will be required to achieve a full-MOX core. In addition, two or more enrichment zones may be used for fuel bundles. Figures 2.19 and 2.20 provide examples of possible bundle configurations. Figure 2.21 provides a loading pattern for a full-MOX core at the equilibrium cycle. (Figures 2.19–2.21 were provided by Westinghouse Electric Corporation, Energy Systems, Nuclear Development Programs.)

The plutonium disposition rate and pertinent fuel cycle characteristics for one reactor are provided in Tables 2.29 and 2.30. A total of 50 MT of plutonium is irradiated over the 9.8-year loading period, according to the schedule shown in Table 2.31. Sequential loading of a total of 2756 MOX fuel assemblies is required to complete the mission. Subsequently, the last reload consists of 68 MOX assemblies along with 16 LEU fuel assemblies. The last MOX bundle will exit the reactor 14.3 years after the start of the mission.

Table 2.32 lists the entire process batch characteristics of each processing section shown in Fig. 2.12.

Fuel Storage Pool (Postirradiation)—Spent fuel assemblies removed from the reactor will be stored underwater in the spent fuel pool while awaiting disposition. The spent fuel storage racks will be located at the bottom of the pool at a depth sufficient to provide adequate radiation shielding. The racks will be designed to protect the fuel assemblies from any impact damage and to withstand potential seismic loadings.

Part of the planning basis is that the irradiated MOX fuel assemblies would be allowed to cool on the reactor site for a period of 10 years. Although U.S. commercial power plants are typically designed to store at least 10 years' worth of spent fuel, the storage pools in most plants are expected to reach their capacity during the next decade. Thus, it is probable that some storage of spent fuel external to the reactor building would be required before the plutonium disposition mission could be completed. If this is the case, the final on-site transfer of MOX spent fuel would be from the spent fuel pool to the dry storage area, as indicated by the final step in the process diagram, Fig. 2.12.

Dry Spent Fuel Storage—The planning basis for facility layout associated with this study includes provisions for the dry spent fuel storage area. However, the relatively small costs associated with this storage were not included in the cost analyses.

Commercially available dry spent fuel management systems are currently licensed and in service at several U.S. reactor sites. The system employs ventilated reinforced concrete horizontal storage modules (HSMs) to store spent fuel assemblies that are sealed in stainless steel dry shielded canisters (DSCs). Each HSM has internal flow passages to promote natural convection cooling for the enclosed DSC. The DSC serves as the containment pressure boundary and provides a leak-tight inert atmosphere for the enclosed fuel assemblies.

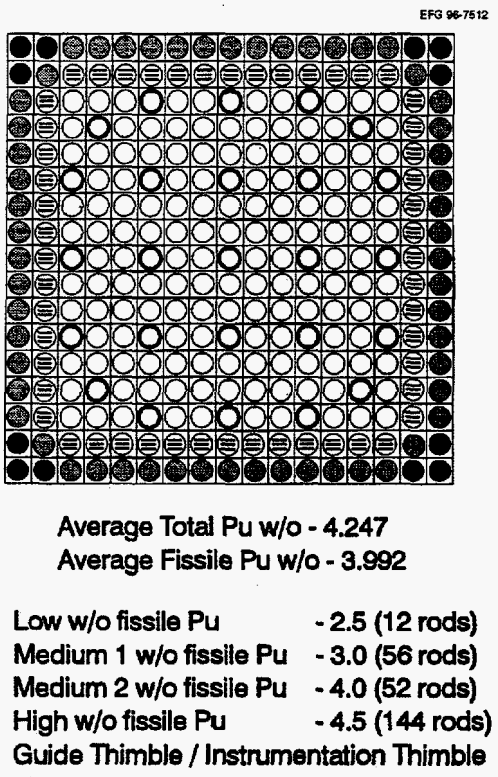


Figure 2.19. Enrichment zoning for low reactivity weapons-grade MOX fuel assemblies in partial weapons-grade MOX core

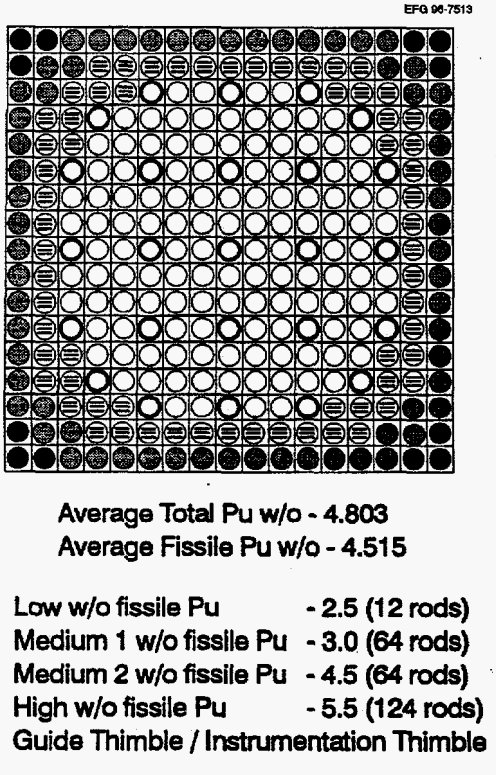
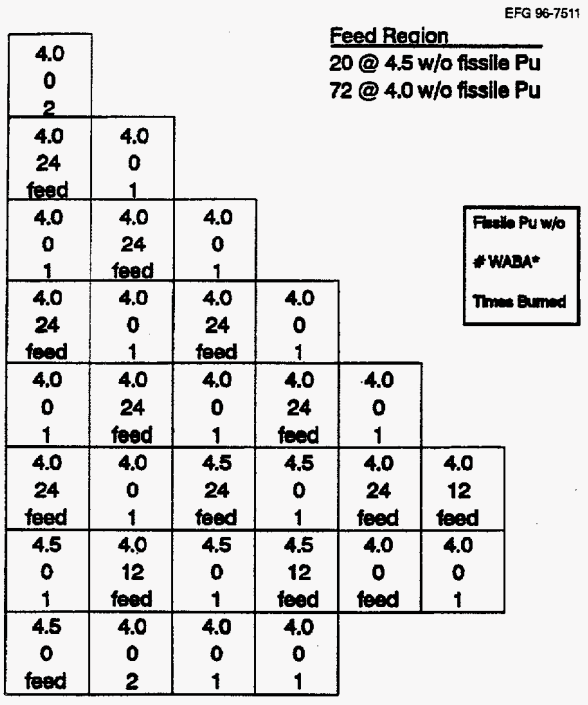


Figure 2.20. Enrichment zone for high reactivity weapons-grade MOX fuel assemblies in partial weapons-grade MOX core



* WABA = Wet Annular Burnable Absorber

Figure 2.21. Full weapons-grade MOX fuel equilibrium cycle core design

Table 2.29. Plutonium disposition capacity and rate for a single Westinghouse reactor

Plutonium per assembly (kg)	18.15
Plutonium dispositioned per year (MT) (average)	1.0
Plutonium dispositioned per full cycle (MT)	1.5

Table 2.30. Westinghouse MOX fuel cycle characteristics

Total cycle duration (d)	548
Effective full-power days per cycle (d)	438
Planned/unplanned outage time (d)	110
Reload batch size (assemblies)	84
Full core size (assemblies)	193
Average discharge exposure (MWd/kgHM)	45.0

Table 2.31. MOX charging/discharging schedule for the existing LWR base-case reactors

Time from MOX load in first reactor (years)	Assemblies loaded in reactor						Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	5	Cumulative			
0.0	84					84	1.5	35.4	
0.4		84				168	3.0	70.9	
0.8			84			252	4.6	106.3	
1.1				84	84	420	7.6	177.2	
1.5	84					504	9.1	212.7	
1.9		84				588	10.7	248.1	
2.3			84			672	12.2	283.6	
2.6				84	84	840	15.2	354.5	
3.0	84					924	16.8	389.9	
3.4		84				1008	18.3	425.4	
3.8			84			1092	19.8	460.8	
4.1				84	84	1260	22.9	531.7	
4.5	84					1344	24.4	567.2	84
4.9		84				1428	25.9	602.6	168
5.3			84			1512	27.4	638.1	252
5.6				84	84	1680	30.5	709.0	420
6.0	84					1764	32.0	744.4	504
6.4		84				1848	33.5	779.9	588
6.8			84			1932	35.1	815.3	672
7.1				84	84	2100	38.1	886.2	840
7.5	84					2184	39.6	921.6	924
7.9		84				2268	41.2	957.1	1008
8.3			84			2352	42.7	992.5	1092
8.6				84	84	2520	45.7	1063.4	1260
9.0	84					2604	47.3	1098.9	1344
9.4		84				2688	48.8	1134.3	1428
9.8			68			2756	50.0	1163.0	1512

Table 2.31. MOX charging/discharging schedule for the existing LWR base-case reactors (cont.)

Time from MOX load in first reactor (years)	Assemblies loaded in reactor						Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	5	Cumulative			
10.1									1680
10.5									1764
10.9									1848
11.3									1932
11.6									2100
12.0									2184
12.4									2268
12.8									2352
13.1									2520
13.5									2604
13.9									2688
14.3									2756

NOTES:

1. Weapons-grade plutonium enrichment = 4.3%.
2. Plutonium per assembly = 18.14 kg.
3. HM per assembly = 421.4 kg.
4. Reload batch size = 84 assemblies.
5. Assemblies per core = 193.
6. Plutonium throughput per year = 4.95 MT (average).
7. HM throughput per year = 118 MT (average). HM throughput used for MOX plant sizing = 118 MT/year.
8. Cycle times including allowance for 80% capacity factor: Refueling cycle time = 1.5 years. Fuel in-core residence time = 4.5 years.
9. Average discharge exposure = 45,000 MWd/MT.
10. At 9.8 years, reactors transition to LEU fuel. The 9.8 years also defines the "mission time" from a nonproliferation perspective (i.e., all of the weapons-capable plutonium is now in a reactor and inaccessible).
11. The first-in, last-out (FILO) loading duration is 14.3 years. This duration is the basis for the incremental operations cost in the cost section.

Table 2.32. PWR facility batch process data

Process box	Process cycle data	Data (average)[a]
Fresh MOX fuel storage and handling	Plutonium throughput (kg) HM throughput (MT) Cycle time[b] (years)	1524 35.4 1.5
Irradiation in reactor	Plutonium throughput (kg) HM throughput (MT) Cycle time (years)	1524 35.4 4.5
Fuel storage pool (postirradiation)	Plutonium throughput (kg) HM throughput (MT) Cycle time (years)	1067 35.4 10.0
Dry storage of spent fuel	Plutonium throughput (kg) HM throughput (MT) Cycle time[c] (years)	1067 35.4 10.0

[a]Data given are per reactor.
[b]Fresh MOX fuel would reside in the fuel storage and handling facility for up to one full fuel cycle (1.5 years).
[c]Assume that dry storage of the spent fuel is needed for the Westinghouse reactors for at least 10 years.

This facility can be located adjacent to or inside the same guarded security area as the new fuel storage vault.

2.4.4.3 Existing LWR Facility Operations Schedule

The LUAs are loaded into the first unit as soon as they are available and during a normal refueling period for the reactor. After completion of the LUA review during the second irradiation cycle, the first mission fuel is loaded at the next scheduled refueling period in May 2010. The MOX fuel loading and discharge schedule for the five reactors is shown in Table 2.31. After the spent fuel assemblies are discharged from the reactors, they are stored in the spent fuel storage pool for 10 years before being shipped to the HLW repository facility. The existing LWR facilities' operational schedule is shown in Table 2.33 and as a part of Sect. 2.4.6.

2.4.4.4 Existing LWR Facility Operations Cost

Table 2.34 shows the costs for the additional staff and materials needed for the plutonium disposition mission above the normal staffing and materials for operation on LEU fuel. The DOE-FMDP is assumed to reimburse the PWR utility for these costs. It is estimated that only 10–12 total additional staff (half direct and half indirect assumed) will be needed in the following areas: security, accountability, in-reactor staff, and common services and training. These additional people will likely be needed for all 14.3 years that MOX resides in the reactors. Thus the category 13 cost is based on that number of years [14.3 years represents the time from the first MOX load to the last MOX load discharge, that is, first in, last out (FILO) as shown in Table 2.31]. The cost of the additional staff and their support materials and equipment materials is costed in category 13 at $7.0M/year for all five reactors. D&D of the reactors (category 20) is the responsibility of the U.S. PWR utility at the end of the reactor life and involves no federal funds. (It is assumed that the use of MOX fuel introduces no special considerations that would affect the D&D costs for the five reactors.)

Because the reactors are not owned by the U.S. government, no revenues accrue, and zero is shown in category 21. The incentive fee to the PWR utility (category 22) is calculated on the basis of 25M/year/reactor pair for the first 5 years followed by $10M/year for the remaining years.

The number of years (9.8) employed for the calculation of the fee is not the same as for the incremental operation (14.3). The fee is based on reactors assumed to have all MOX initial assemblies with no ramp-ups or ramp-downs in assembly loading. If the mission were done this way, the number of equivalent "all MOX" assembly years would be approximated by the defined mission time of 9.8 years (first load in to last

Table 2.33. Existing LWR facility operations schedule

Task name	Duration (months)	Start	Finish
Reactor "Ready" to Accept MOX			2/2004
Fuel Qualification	54	6/2007	12/2011
LUA Arrives			6/2007
LUA Irradiation	54	6/2007	12/2011
Reactor Facility(-ies) Operation	171	5/2010	8/2024
Unit 1 Loading Duration	108	5/2010	5/2019
Unit 2 Loading Duration	108	10/2010	10/2019
Unit 3 Loading Duration	108	2/2011	2/2020
Units 4 & 5 Loading Duration	88	7/2011	11/2018
Last Assemblies—Single Cycle	18	3/2020	8/2021
Last Assembly Discharged	54	3/2020	9/2024
Spent Fuel Storage	237	12/2014	9/2034
First MOX in Spent Fuel Pool	120	12/2014	12/2024
Last MOX in Spent Fuel Pool	120	9/2024	9/2034

Table 2.34. Other LCCs for five-LWR reactor facility

Category	Cost category description	Lump sum (1996 $M)	Annual (1996 $M/year)
	Years for fee and transportation = 9.8; years for staffing cost assessment = 14.3		
	Other LCCs:		
13	Operations and maintenance staffing (incremental for 14.3 years)	100	7.0
14	Consumables including utilities (included in category 13)	0	
15	Major capital replacement or upgrades	*a*	
16	Waste handling and disposal	*a*	
17	Oversight	*a*	
18	M&O contractor fees	*a*	
19	Payments-in-lieu-of-taxes to local communities	*a*	
20	D&D	*a*	
21	Revenues (if applicable) from sale of MOX or electricity	0	
22	Fees to privately owned facility (based on 9.8 FMLE[b] years)	433	44.2[c]
23	Transportation of plutonium forms to facility (based on 9.8 years)	26	2.7 [c]
24	Storage of plutonium at existing 94-1 site facility	N/A	N/A
	TOTAL OTHER LCC	$559	*d*

[a]No incremental expenditure required or not applicable to existing privately owned reactors.
[b]Full-MOX load equivalent (FMLE) based on first load in to last load in mission duration (9.8 years).
[c]Averaged over 9.8 years.
[d]Total annual recurring costs are not calculated; in reality, annual costs will not be same for each year of the 14.3 years of the (first-in/last-out) mission duration. During the first 9.8 years, the total annual costs would exceed $53M/year

load in). The incentive fee is not included for this variant in Table 4-1 of the *Technical Summary Report* because it is a business-negotiable item. (See Appendix H for TSR discussion.)

Approximately $2.7M/year in transportation costs has been calculated for transportation of MOX fuel bundles. The MOX fuel fabrication facility is assumed to be located in the southeastern United States, and the five PWRs are assumed to be located in the midwestern United States. (These locations are for purposes of transportation cost calculations only. No sites have been selected.) If the fee and transportation are included, the reactor part of the five-LWR plutonium disposition mission will cost on average over $53.9M/year during the first 9.8 years of the reactor mission.

2.4.5 Existing LWR Facility Conversion to LEU Fuel

2.4.5.1 Existing LWR Facility Conversion to LEU Fuel Schedule

The last MOX fuel core load occurs in the third reactor (Table 2.31) and comprises 68 MOX fuel assemblies; the other 16 fuel assemblies are LEU fuel assemblies. Subsequent core loads are all LEU fuel.

2.4.5.2 Existing LWR Facility Conversion to LEU Fuel Cost

For this analysis, a conversion to LEU cost of $0 was assumed. Section 2.4.4.4 provides a description of all final costs. No ramp-up or ramp-down/conversion costs were assumed.

2.4.6 Existing LWR Facility Schedule Summary

The overall existing LWR facility implementation schedule is summarized in Table 2.35 and shown in Fig. 2.22. This facility schedule is also shown in the discussion of the overall alternative schedule in Sect. 2.6.1. The critical path for this facility (shown in Fig. 2.22) is the availability of the LUAs. The reactors are ready to accept MOX LUAs more than 3 years before the MOX LUAs are available.

2.4.7 Existing LWR Facility Cost Summary

Summary of Reactor Facility LCCs—Table 2.36 shows a summary of the existing LWR facility LCCs in the 24-category format. All anticipated reactor-related costs from FY 1997 forward are included in this table. Section 2.6.2 of this report compares these

Table 2.35. Existing LWR facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Utility Selection	12	12/1998	12/1999
Licensing and Permitting	51	12/1999	2/2004
LUAs Arrive from MOX facility			6/2007
Fuel Qualification—LUAs	54	6/2007	12/2011
Reactor Modifications	48	12/1999	11/2003
Unit 1 Loading Duration	108	5/2010	5/2019
Unit 2 Loading Duration	108	10/2010	10/2019
Unit 3 Loading Duration	108	2/2011	2/2020
Units 4 and 5 Loading Duration	88	7/2011	11/2018
Last Assemblies—First Cycle	18	3/2020	8/2021
Spent Fuel Storage	237	12/2014	9/2034

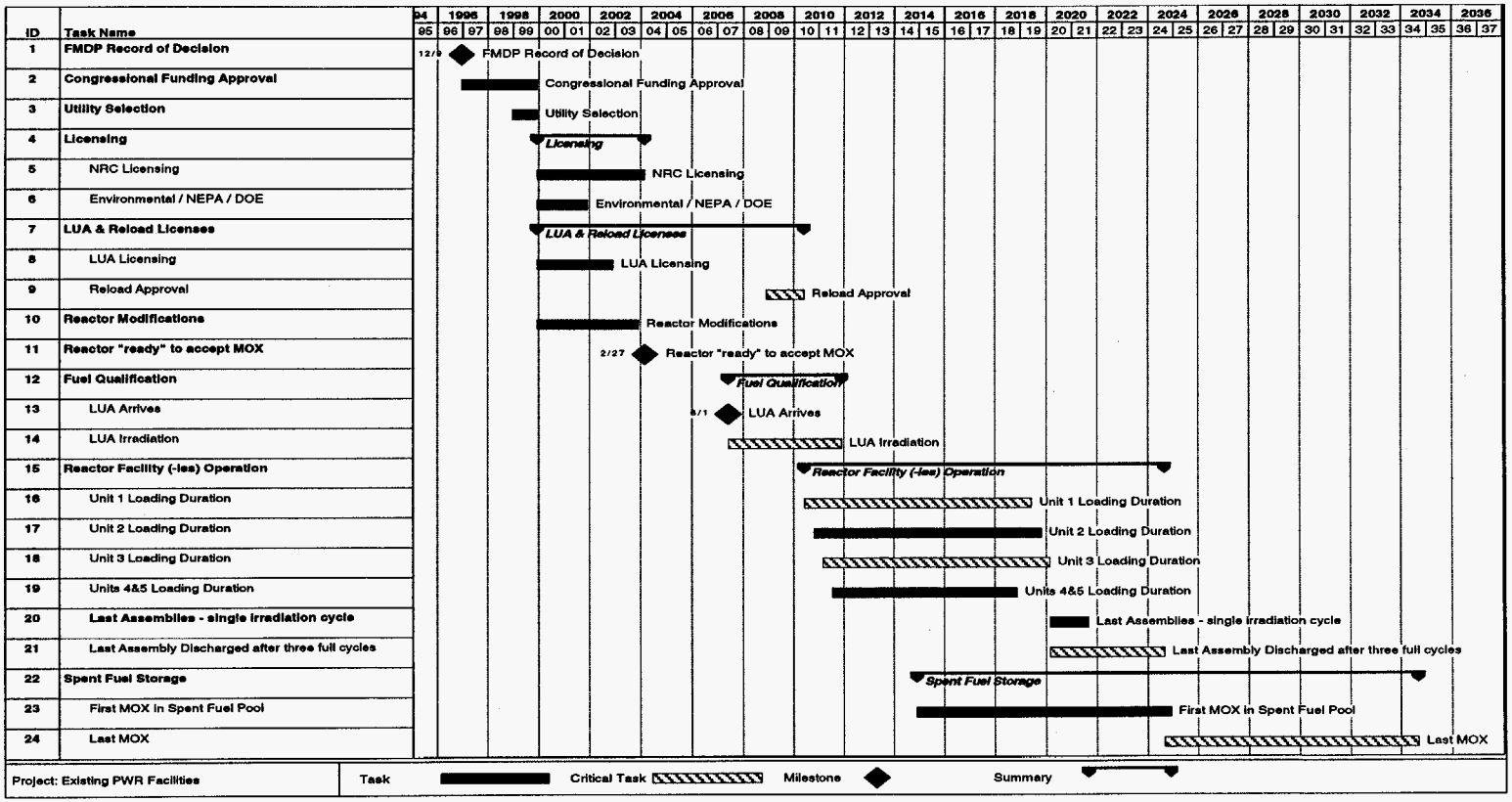


Figure 2.22. Existing LWR facility schedule summary

Table 2.36. Summary of LCCs for five existing LWR facilities

Category	Cost category description	Cost [lump sum (1996 $M)]	Annual (1996 $M/year)
	Preoperational or OPC up-front costs:		
1	R&D	36	
2	NEPA, licensing, permitting	103	
3	Conceptual design	1	
4	QA, site qualification, S&S plans	2	
5	Postconstruction startup	22	
6	Risk contingency	0	
	TOTAL OPC	$164	
	Capital (TEC up-front costs):		
7	Title I, II, III engineering, design, and inspection	10	
8	Direct and indirect construction/modification	58	
9	Construction management (percentage of category 8)	0	
10	Initial spares	0	
11	Allowance for indeterminates (AFI) (percentage of categories 7–10)	0	
12	Risk contingency	0	
	TOTAL TEC	$68	
	TOTAL UP-FRONT COST (TPC)	$232	
	Other LCCs		
13	O&M staffing (incremental)	100	7.0
14	Consumables including utilities	0	
15	Major capital replacements or upgrades	0	
16	Waste handling and disposal	0	
17	Oversight	0	
18	M&O contractor fees	0	
19	Payments-in-lieu-of-taxes to local communities	0	
20	D&D	0	
21	Revenues (if applicable)	0	
22	Fees to privately owned facility	433	44.2
23	Transportation of plutonium forms to facility	26	2.7
24	Storage of plutonium at existing 94-1 site facility	0	
	TOTAL OTHER LCC	$559	53.9[a]
	GRAND TOTAL ALL LCC	$791	

Note: Reactor incremental staffing is based on 14.3 years; transportation and fee are based on 9.8 years.
[a]Annual cost for first 9.8 years.

1996 constant-dollar LCCs (along with the discounted LCCs) with those for other facilities needed for the overall base LWR option.

Reactor-related LCCs total to $791M, most of which are for fee, operations, and transportation ($559M). Up-front costs account for $232M of the total.

2.4.8 Existing LWR Facility S&S Summary

Possible Diversion, Theft, or Proliferation Risks—Although fresh MOX fuel assemblies (two or more) are considered Category IC SNM (Table 2.12), they are only a moderately attractive target for overt theft. As for the MOX fuel fabrication facility, the likelihood of covert theft of fresh MOX fuel is low. The large mass and dimensions of the fuel assembly will require the use of special handling equipment, which will provide increased delay against an overt attack and also help in detecting any covert adversary activities. The fresh fuel assemblies will be stored in a vault-like area or possibly a storage pool where enhanced delay and access control measures are in place. As in the MOX fuel fabrication facility, the risk for overt theft will be medium. Once the fuel assemblies are placed into the reactor core, not only will they be inside the reactor containment building, but also their intrinsic barriers will increase significantly once they have been irradiated. Upon irradiation, they will become Category IVE SNM and will be a low attractiveness target for both overt and covert theft.

The irradiated fuel assemblies within the storage pool will be a low covert and overt theft risk because of the attributes mentioned above. If the fuel assemblies are placed into dry spent fuel storage, they will still have significant irradiation, and when they are placed in the storage containers (DSCs) they will be almost impossible to move without being detected. If after sufficient time the fuel assemblies are no longer self-protecting (100 rem/h at 1 m), the material could become Category IID. The fuel assemblies still, however, would not be a particularly high theft target because of the significant external barriers in place.

Environmental Conditions—Fuel assemblies will remain at the reactor at least 180 months—60 months for receipt, fresh fuel storage, and burnup in the reactor core and 120 months in a spent fuel storage pool. It is also possible that the assemblies could remain onsite in a dry spent fuel storage configuration. The fresh fuel will be stored in a separate building, and the only intrasite transport will involve moving the fuel from the storage area to the storage pool for loading into the reactor core. No fissile material waste streams are generated.

The fuel assemblies will remain in the reactor core for three fuel cycles. Spent fuel will be stored first in the storage pool and then, if dry storage is necessary, in DSCs, which are stored in HSMs. Although the inventory of MOX fuel may be large and may exceed Category I quantities for fresh MOX fuel, and although the throughput may be large, the number of process steps and the complexity of the operations concerning the fuel are relatively low. The material consists of discrete items that usually reside for long periods at a single reactor location (e.g., reactor core, spent fuel pool, dry storage area). Table 2.37 provides information about the material flow of plutonium through this facility and describes the material and its attractiveness level.

Material Form—The fresh MOX fuel is Category IC; once it is irradiated and becomes self-protecting, it becomes Category IVE. This category provides a very high radiological barrier. In addition, the assemblies are quite massive, and from the standpoint of plutonium isotopics the material becomes much less desirable than fresh MOX fuel. Because of the presence of highly radioactive fissile products, chemical processing to convert the material into a weapons-usable form is much more difficult. The radiological and isotopic attributes are time- dependent, and eventually the material would no longer be self-protecting.

S&S Assurance—Item accountancy is used to account for fuel assemblies. Markings and seals on the assemblies can also be used to verify material. Special handling equipment is required to move these assemblies and once they have been irradiated, remote handling is necessary. The material in general is not very accessible. For spent fuel, some NDA measurements are possible, but currently they are generally used to confirm the presence of the spent fuel and not to accurately account for the material. The quantity of material can be estimated using the initial material information and the records from the reactor facility.

Potential Risks of Diversion—The fresh MOX fuel assemblies are relatively easy to account for using item accountancy. Along with C/S measures, the likelihood for covert diversion is medium. The low concentration of plutonium in the fuel, plutonium isotopics, and the high radiological barrier make diversion more difficult. Once the fuel has been irradiated,

Table 2.37. Nonproliferation and S&S risk assessment for the existing LWR base-case facility

Environment							
Facility	**Activity**	**Duration (years)**	**Throughput plutonium**	**Waste streams**	**Maximum plutonium inventory**	**Intrasite transport**	**Barriers**
Reactor (data for one reactor; five reactors used in alternative)							1 PA VA/MAAs
	Fresh MOX fuel storage and handling	1.5 (cycle)	1524-kg batch 60-kg ^{235}U batch 84 assemblies/load	No	97 containers; 193 assemblies fresh fuel on-site	Yes—transfer to reactor core from storage via fuel transfer tube	Separate stand-alone building, TIDs
	Reactor (0.70 plutonium burnup)	9.8	1.0 MT/year 1524 kg/year (fresh) 193 assemblies	No	18.15 kg/ assembly; 193 assemblies/ core	No	Containment building
	Fuel storage pool (postirradiated)	10	1067 kg	No	7 MT	No	In fuel storage basin
	Dry spent fuel storage	10		No		Yes (to dry storage)	LA 40 HSMs
Transport	Reactor to repository						

Note: PA—protected area.
MAA—material access area.
LA—limited area.

Table 2.37. Nonproliferation and S&S risk assessment for the existing LWR base-case facility (cont.)

Material form										
Facility	**Activity**	**SNM input**	**SNM output**	**Quantity**	**Concentration of plutonium/ HM**	**SNM category[a]**	**Item mass/ dimensions**	**Radiation barrier**	**Chemical composition**	**Isotopics**
Reactor						DUU DUI				
	Fresh MOX fuel storage	MOX fuel assemblies (fresh)	MOX fuel assemblies (fresh)	18.15 kg plutonium/ assembly; 193 assemblies/ core	18.15 kg/ 422 kg HM (0.002 g ^{233}U)	IC	522 kg, 4.1 × 0.22 m	No	MOX	0.936 ^{239}Pu 0.059 ^{240}Pu/ assembly
	Reactor	MOX fuel assemblies (fresh)	MOX fuel assemblies (irradiated)	2451 kg plutonium (irradiated)		IC (in) IVE (out)		No (in) Yes (out) 3×10^6	MOX	At discharge 0.488 ^{239}Pu 0.289 ^{240}Pu 0.160 ^{241}Pu 0.042 ^{242}Pu
	Fuel storage pool (irradiated)	MOX fuel assemblies (irradiated)	MOX fuel assemblies (irradiated)	588 irradiated assemblies; 7466 kg plutonium (irradiated)		IVE or IID if moderately irradiated		Yes 2.1×10^4		At 10 years 0.521 ^{239}Pu 0.309 ^{240}Pu 0.106 ^{241}Pu 0.045 ^{242}Pu
	Dry spent fuel storage	MOX fuel assemblies (irradiated)	MOX fuel assemblies (irradiated)			IVE or IID if moderately irradiated		Yes		
Transport	Reactor to repository									

[a]Table 2.12 provides attractiveness levels.

Note: SNM—special nuclear material.
DUU—direct-use unirradiated.
DUI—direct-use irradiated.

Table 2.37. Nonproliferation and S&S risk assessment for the existing LWR base-case facility (cont.)

S&S								
Facility	**Activity**	**No. of MBAs**	**Type accounting system**	**Nuclear measurement method**	**Classified material**	**Physically accessible**	**Access**	**Special handling equipment**
Reactor		1–2	100% Item	Measure one nuclear attribute				
	Fresh MOX fuel storage		Item	2% (fresh—domestic) 3% (fresh—international)	No proprietary	No	Hands-on remote	Yes, cask handling crane, fuel handling machine
	Reactor		Item		No	No		Yes, refueling platform
	Fuel storage pool		Item	6% (irradiated—domestic) 10% (irradiated—international)	No	No		
	Dry spent fuel storage		Item		No	No		
Transport	Reactor to repository							

Note: MBAs—material balance areas.

its attractiveness for reuse is significantly reduced, and the threat of diversion is low.

Difficulty of Diversion, Retrieval, Extraction, and Reuse—Fresh fuel assemblies pose a moderate risk for diversion and reuse. Once the fuel has been irradiated, the radiological barrier makes handling the material more difficult; thus, the risk of diversion and reuse is low. The fresh and the irradiated MOX fuel are maintained at single locations (e.g., reactor core, spent fuel pool) for long periods of time, which makes diversion more difficult.

Assurance of Detection of Retrieval and Extraction—The fresh fuel would have the same moderate diversion risk as at the end of the fuel fabrication facility. Once the fuel has been irradiated, it will require special handling equipment, and the intrinsic radiological barrier will reduce the risk of diversion to low. Strict accountancy along with containment and surveillance will be maintained.

2.4.9 Existing LWR Facility Technical Viability

Technological Maturity—Given that technology is defined as a technical method of achieving a practical purpose, the technologies present in the reactor facility are as follows:

1. methods of fuel receipt, inspection, and accountability;
2. method of fresh fuel storage;
3. method of fresh fuel transfer to reactor and loading to core;
4. reactor operation to consume plutonium;
5. balance-of-plant (BOP) operation not related to fuel handling;
6. method of unloading core and spent fuel transfer;
7. method of wet spent fuel storage;
8. method of transfer from wet to dry spent fuel storage;
9. method of dry spent fuel storage; and
10. method of fuel transfer to spent fuel cask.

These ten technologies correspond to physical operations involved in the placement of MOX fuel in differing physical areas of the plant.

Assessment of the development level of these technologies requires evaluations based on one or more of the following engineering analyses:

1. Steady-state analyses
   i. Thermal hydraulics
   ii. Reactor physics
   iii. Reactivity control
   iv. Fuel chemistry and thermodynamics
   v. Fuel structural mechanics
2. Transient analyses
   i. Accident scenarios
   ii. Reactor response (including 1.i.–v)

Additional input related to the development level can be obtained from known R&D needs itemized later in this section.

1. Fuel receipt, inspection, and accountability—Fuel receipt and inspection will occur at fresh fuel storage, which is located inside the ex-reactor fuel storage complex. Proposed in-reactor fuel inspection stations should be adequate for MOX fuel.

   Because only additional analyses are required (no additional experimental data are needed) and experience in foreign reactors indicates that the analyzed operation would be successful and licensable, these technologies are judged to be at the *commercial* stage even though no MOX fuel operations are currently being conducted in the United States.

2. Method of fresh fuel storage—Wet pool storage arrays designed for LEU fuel are judged adequate for MOX fuel storage. Validation of criticality safety analyses is required but could likely be accomplished with the provision of existing data from foreign reactors. This technology is judged to be at the *commercial* stage of development.

3. Method of fresh fuel transfer to reactor core—Overhead cranes are used to transfer fresh fuel from the storage pool to the reactor. No complications are expected from the use of MOX fuel. The technology is judged to be at the *commercial* stage of development.

4. Reactor operation to consume plutonium—No new technology needs were identified for the

reactors. Irradiation and analysis of MOX fuel rods and LTAs are planned to qualify the rod fabrication process and to further benchmark the nuclear design codes. (See the "R&D Needs" subsection.)

Based on vendor comments, the identified R&D needs, the existence of European reactors operating on one-third MOX fuel, and the programmatic goal of operating a full core of MOX fuel, this technology is judged to be at the prototype stage of development.

5. BOP operation not related to fuel handling—There are no licensing impacts on the design of the steam supply system of the plant. This technology is judged to be at the *commercial* stage of development. However, R&D items call for additional analyses potentially related to the BOP design.

6. Method of unloading core and spent fuel transfer—The method is the same as for transfer of fresh fuel to the reactor (overhead crane). Spent fuel has heat transfer and shielding considerations not present with fresh fuel, but the differences from the existing fuel cycle are believed to be insignificant. Consequently, the technology is at the *commercial* stage of development.

7. Method of wet spent fuel storage—Spent fuel is stored in water-filled pools where the water provides both cooling and shielding. Analyses will be required to certify proposed spent fuel storage pools, but needed experimental data exist and considerable foreign experience is available. This technology is judged to be at the *commercial* stage of development.

8. Method of transfer from wet to dry spent fuel storage—The method of transfer from wet storage to shipping cask has been demonstrated and is believed to be independent of the type of cask. Consequently, this technology is judged to be at the *commercial* stage of development.

9. Method of dry, spent fuel storage—The method of dry spent fuel storage is assumed to be storage in some type of large canister. This method is judged to be *commercial*, although new analyses and certification will be required.

10. Method of fuel transfer to spent fuel cask—The method of transfer from wet storage to shipping cask has been demonstrated and is believed to be independent of the type of cask chosen for shipment of the fuel. If dry storage is employed, the fuel will already be in shipping casks. This technology is judged to be at the *commercial* stage of development, although additional analyses will be required.

Technical Risks—Assuming that implementation of any activity not currently operational involves some minimal degree of risk (technical, financial, regulatory, and/or schedule), risk is herein quantified as minimal, low, medium, or high for each of the technologies. All of those technologies determined to be commercialized either domestically or internationally have only minimal implementation risks discussed as follows.

1. Methods of fuel receipt, inspection, and accountability—These technologies have been determined to be commercialized because they are currently implemented domestically with LEU and internationally with MOX fuels. However, domestic implementation of these technologies with MOX fuel involves some degree of risk. Based on the state of the technology, the risks involved are minimal.

2. Method of fresh fuel storage—Although some differences exist between handling MOX fuel and LEU fuel, none of these differences are expected to introduce excessive risk. This technology is commercialized domestically with LEU fuels and internationally with MOX fuels. The technical risk associated with adopting the existing technologies to domestic MOX fresh fuel storage is minimal.

3. Method of fresh fuel transfer to reactor core—This technology is fully developed. Risk associated with this technology is minimal.

4. Reactor operation to consume plutonium—MOX fuel has been irradiated both domestically and internationally. However, the irradiation experience base does not cover all of the issues associated with MOX irradiation as part of this plutonium disposition mission. For this reason, the technology has been judged to be at the prototypic stage of development. The outstanding issues are potential inclusion of gallium impurities in the fuel matrix, presence of americium in the MOX fuel, use of weapons-grade rather than reactor-grade plutonium, severe accident performance of the fuel, and use of a full-MOX core rather than ~1/3-core. None of these issues are judged to be impossible to overcome. The best evidence available suggests in fact that the MOX performance

should equal or exceed the performance of similar LEU fuel.

5. Gallium is added to weapons-grade plutonium as an alloying agent (1 wt %). It has been suggested that some gallium may remain in the plutonium and carried through to the MOX fuel. Preliminary evidence suggests that the gallium may not cause problems during irradiation. Because the gallium concentration would be several orders of magnitude greater than that generated as a fission product, additional fuel development work would be required.

6. Americium, another impurity present in weapons-grade MOX, forms from radioactive decay of ^{241}Pu. Its presence increases the shielding requirements for the MOX fuel. However, weapons-grade plutonium (by definition) includes low percentages of the higher plutonium isotopes, including ^{241}Pu. The resulting americium content is actually lower than that encountered in commercial MOX fuel that has been stored for a few years since reprocessing.

   Most of the MOX fuel that has been irradiated used reactor-grade MOX, which has a lower fissile content than weapons-grade. The variation in ^{240}Pu content is not expected to cause difficulties because fertile materials, such as ^{238}U, or integral neutron absorbers could be used to adjust reactivity.

   The severe accident performance of MOX fuel has not been experimentally validated. However, at the end of its life, UO_2 fuel contains an appreciable quantity of plutonium. For this reason and because the homogeneity of modern fuels causes them to behave similarly to UO_2 fuels in most respects, the severe accident behavior of MOX fuel is expected to be within the uncertainty bands of the UO_2 behavior. Demonstration tests may be required, but the tests can be performed on sections of LTA fuel rods after irradiation.

   Thus, although issues associated with reactor operation do exist, none of the issues presented are judged to add significant risk to the overall mission success. Even if the performance is not as expected, engineering solutions can be found for the difficulties. The overall risk associated with reactor operation to irradiate plutonium is judged to be low.

7. BOP operation not related to fuel handling—The risk associated with BOP operation is therefore judged to be minimal.
8. Method of unloading core and spent fuel transfer.
9. Method of wet spent fuel storage.
10. Method of transfer from wet to dry spent fuel storage.
11. Method of dry spent fuel storage.
12. Method of fuel transfer to spent fuel cask.

Because spent MOX fuel is very similar to spent UO_2 fuel, the technologies associated with spent fuel operations (items 6–10 above) are judged to be at the commercial stage of development. All of these spent fuel technologies have been demonstrated domestically for UO_2 fuel and internationally for both UO_2 and MOX fuels. The risks associated with implementation of these technologies are therefore judged to be minimal.

R&D Needs—Ten technologies have been evaluated for the reactor facility. The R&D issues for each of those technologies are discussed in the following paragraph.

1. Methods of fuel receipt, inspection, and accountability—These technologies are commercialized domestically for LEU fuels and internationally for MOX fuels. Domestic implementation will require some engineering development to adapt the domestic LEU experience and/or the international MOX experience.
2. Method of fresh fuel storage—Some differences in the handling of fresh MOX fuel vs LEU fuel exist. Adaptation of current LEU fuel and plutonium storage technology should prove adequate so that only minimal technology development is required.
3. Method of fresh fuel transfer to reactor core—Minimal development is required.
4. Reactor operation to consume plutonium—As discussed in the two previous sections, some confirmatory testing will be required to qualify MOX fuel, and some development may prove necessary depending on how the fuel is manufactured. The outstanding issues are potential inclusion of gallium impurities in the fuel matrix, presence of americium in the MOX fuel, use of weapons-grade rather than reactor-grade plutonium, and

severe accident performance of the fuel. Also, some engineering analyses and development will be required to quantify and adjust for changes in the reactor operation necessitated by MOX fuel use.

The irradiation behavior of gallium in MOX fuel is unknown. An irradiation testing program (above and beyond the planned LTA program) will be required to demonstrate adequate behavior. Some engineering work will be required to assess and quantify the changes created by use of weapons-grade rather than reactor-grade MOX fuel. This will include some code validation.

A number of engineering development and R&D tasks have been identified to deal with reactor operation on MOX fuel, with the majority of tasks focusing on fuel development activities.

5. BOP operation not related to fuel handling—Minimal development is expected.
6. Method of unloading core and spent fuel transfer.
7. Method of wet spent fuel storage.
8. Method of transfer from wet to dry spent fuel storage.
9. Method of dry spent fuel storage.
10. Method of fuel transfer to spent fuel cask.

Because spent MOX fuel is very similar to spent LEU fuel, the technologies associated with spent fuel operations (items 6–10 above) are judged to be at the commercial stage of development. All of these spent fuel technologies have been demonstrated domestically for LEU fuel and internationally for both LEU and MOX fuels. Some limited analysis may be required to quantify the differences between the fuels. However, it is unlikely that any appreciable development will be required to accommodate the MOX fuel.

2.5 HLW Repository

2.5.1 HLW Repository Description

The HLW repository process diagram is shown in Fig. 2.23. The repository consists of two facilities: a surface facility for the receipt and handling of the

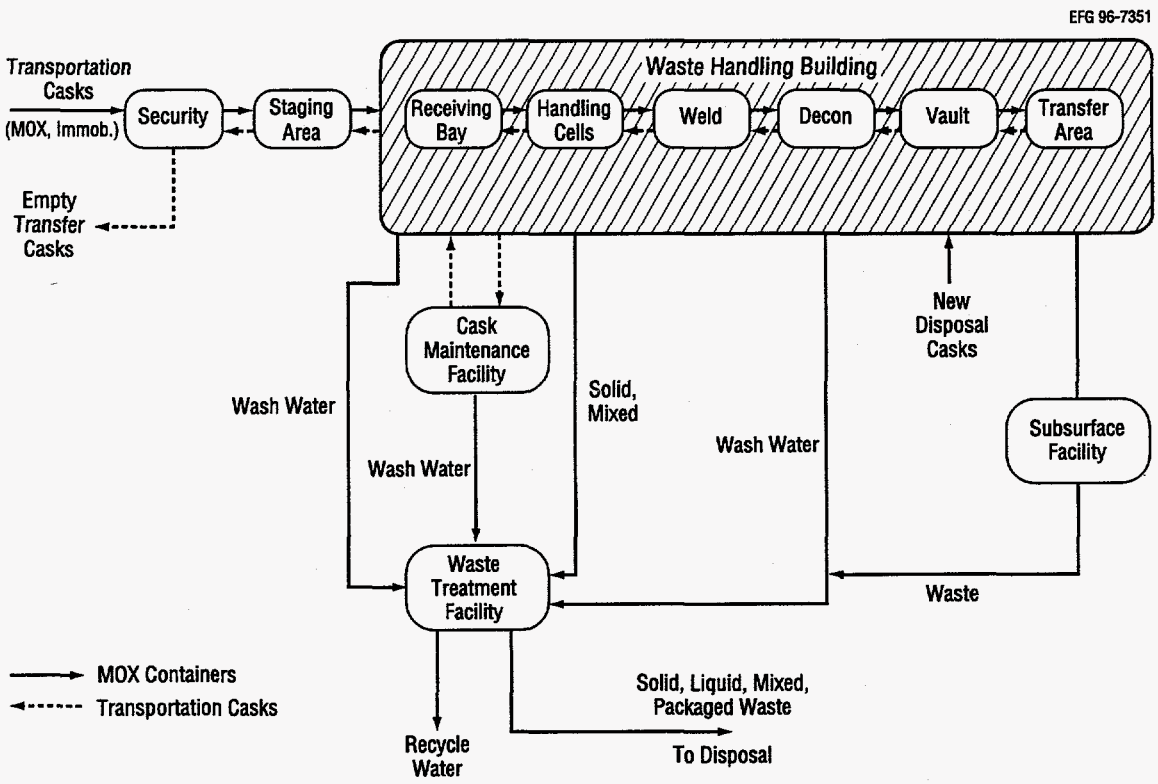


Figure 2.23. Process flow diagram for the repository facility

wastes and a subsurface facility for permanent isolation of the wastes from the accessible environment. The tract of the surface facility is about 90 acres and contains two separate areas: an operations area, containing all facilities for waste handling and radiological control, and a general support facilities area, consisting of "cold" facilities and the supporting infrastructure. These facility sections are described in the following paragraphs.

The geologic disposal of spent fuel is a solids-handling process. As indicated in Table 2.38, the repository facility will receive 132 waste packages containing MOX fuel assemblies. At the repository, the loaded transportation casks containing MOX spent fuel will be inspected and moved to a radiological-controlled area. The casks will enter a waste handling building through air locks where decontamination takes place. Wash water from the decontamination operation will be sent to a waste treatment facility. In a waste handling building, sealed canisters containing MOX spent fuel will be removed from the transportation casks in a hot cell. The canisters will be transferred to disposal containers, and lids will be welded in place. The disposal container will be decontaminated, if necessary, and transferred to a shielded storage vault to await placement into the underground transfer cask. The transfer cask containing the disposal container will be coupled to a transporter and moved underground for final emplacement.

The layouts for a repository surface facility and subsurface facility are shown in Figs. 2.24 and 2.25, respectively.

2.5.2 HLW Repository Design and Construction

2.5.2.1 HLW Repository Design and Construction Schedule

For this analysis, it has been assumed that the construction of the HLW repository will begin in 2005 and will require 5.5 years to complete.

2.5.2.2 HLW Repository Design and Construction Cost

The DOE FMDP is not responsible for any design and construction costs associated with the HLW repository.

2.5.3 HLW Repository Licensing

2.5.3.1 HLW Repository Licensing Overview

A path forward exists for the repository licensing process in accordance with NRC regulations such as CFR 10 Part 60 and Part 2. Disposal of MOX spent fuel may require an amendment to the repository license, with the applicable NEPA process.

2.5.3.2 HLW Repository Licensing Schedule

For this analysis, it has been assumed that the licensing process for this facility will begin in March 2002 and will require 8.5 years to complete.

2.5.3.3 HLW Repository Licensing Cost

The DOE FMDP is not responsible for licensing or any other preoperational costs associated with the HLW repository.

2.5.4 HLW Repository Shipments and Storage

Irradiated nuclear fuel is stored in on-site water pools. Ideally, spent fuel will be removed from the spent fuel pools after a 10-year postirradiation period and transported directly to a geologic repository for emplacement. However, to ensure that the irradiation mission can proceed even in the event that the HLW repository is delayed, the reactor facility also includes a fourth process step whereby spent fuel could be removed from the pools and placed into on-site dry storage in specially designed canisters. Once irradiated, the MOX fuel will no longer be required to be shipped by SST. Instead, it is assumed that the Civilian

Table 2.38. Parameters for spent MOX fuel transport leg

Maximum material/package	Quantity plutonium/campaign (MT)	Estimated number of packages to be shipped	Number of cask shipments/campaign
21 PWR assemblies	~50	132	132

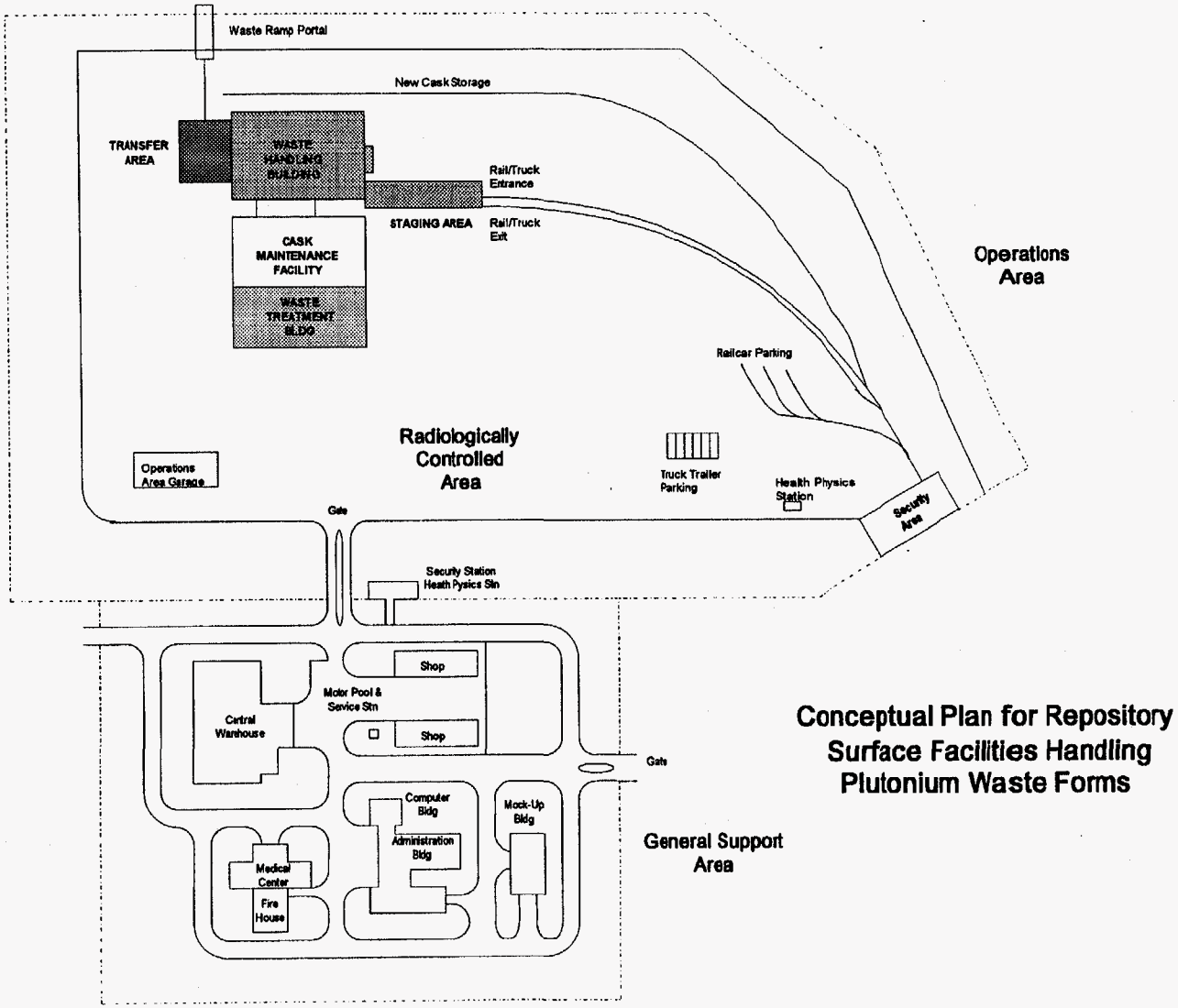


Figure 2.24. Repository surface facility layout

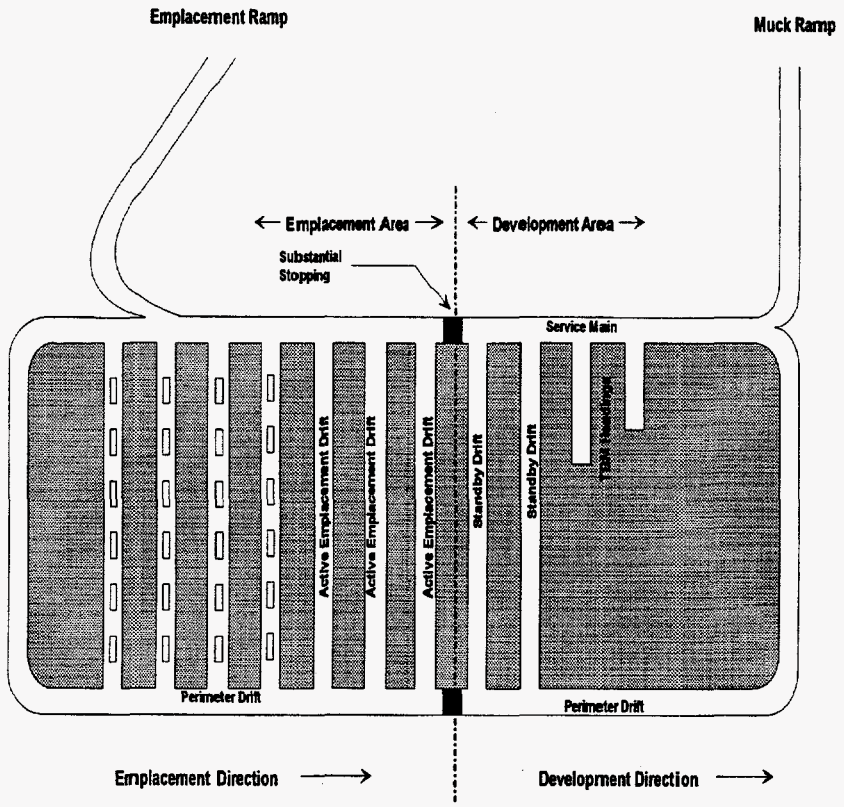


Figure 2.25. Repository subsurface facility layout

Radioactive Waste Management System (CRWMS) transportation system will be used to transport the spent fuel from the reactors to the repository. The CRWMS transportation system includes truck- and rail-based spent fuel cask systems. Some U.S. reactors that cannot accommodate large rail casks will need to use smaller spent fuel casks transported by truck.

Shipment Information—Although beyond the scope of the FMDP mission, the spent fuel will eventually be transported to the geologic repository for emplacement. Table 2.38 provides estimates of the number of shipments required.

2.5.5 HLW Repository Schedule Summary

The HLW repository facility is scheduled to open in 2010. The spent MOX fuel is scheduled to be delivered to the repository facility from December 2024 to September 2034. The HLW repository schedule summary is shown in Table 2.39 and as a part of Fig. 2.26.

Table 2.39. HLW repository facility schedule summary

Task name	Duration (months)	Start	Finish
Licensing Process	102	3/2002	8/2010
Construction	66	3/2005	8/2010
Repository Opening Date			8/2010
Delivery of MOX to Repository	118	12/2024	9/2034
Transportation of first MOX to respository	1	12/2024	12/2024
Transportation of last MOX	1	9/2034	9/2034

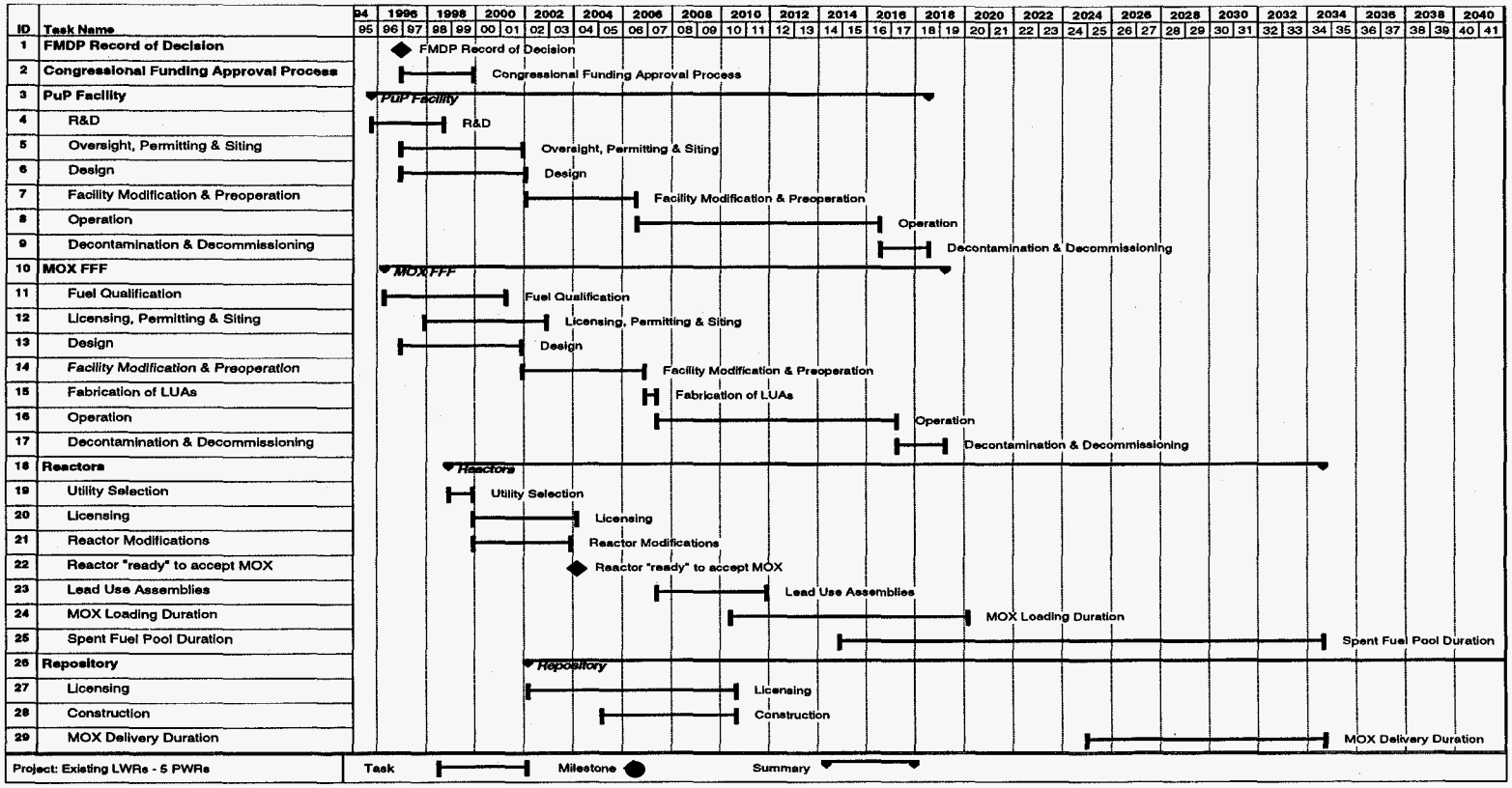


Figure 2.26. Existing LWR alternative base-case schedule summary

2.5.6 HLW Repository Cost Summary

The HLW repository cost to power reactor owners is 1 mill/kWh of power generated and is paid into the nuclear waste fund. The utility pays this fee whether it is using LEU or MOX fuel. The MOX fuel is assumed *not* to impose any additional costs above those covered by the 1-mill/kWh fee paid by the utility. Therefore, the incremental cost to DOE-FMDP is zero.

2.5.7 HLW Repository Technical Viability

Technological Maturity—The technology to handle MOX spent fuels in a surface and subsurface facility is currently available in industry. If it is assumed that a repository is operational when MOX spent fuel is to be emplaced, the maturity of the technology to receive and emplace the waste form is not likely to be an issue.

Technical Risks—The primary risk issue related to emplacement of MOX spent fuel in a repository is associated with the long-term performance considerations. This consideration is necessary to satisfy the licensing requirements of 10 CFR 60. The long-term performance issues comprise (1) releases/doses to the accessible environment, (2) long-term criticality conditions of the as-fabricated waste package, (3) the degraded mode criticality, and (4) the external criticality conditions imposed by introducing the plutonium waste forms into a repository.

The incremental contributions to releases and doses by the MOX spent fuel appear to be small compared with those predicted for uranium-based commercial fuel. However, the cumulative releases and doses from both the commercial and MOX fuels must be shown to be within the envelope permitted by regulations. Because a repository has not yet been licensed, calculations of such cumulative effects have not been performed.

For the case when MOX fuel is irradiated in existing reactors, the as-fabricated reactivity worth within the waste package is such that the k_{eff} value is comparable to commercial SNF. Only a single case examining the degraded mode criticality (within the waste package) has been conducted for existing reactor waste forms. It shows the long-term performance to be acceptable. Other scenarios for degraded mode and external criticality must be examined to ensure that long-term criticality does not disqualify existing reactor waste forms.

R&D Needs—Based on the technical risks discussions previously presented, the primary analyses requirements are to conduct long-term criticality analyses for the degraded and external conditions to determine the viability of emplacing these waste forms into an HLW repository.

2.6 Existing LWR Base-Case Summary

2.6.1 Existing LWR Base-Case Schedule Summary

The existing LWR alternative base-case schedule is a combination of the individual facility schedules previously discussed. This overall schedule is summarized in Table 2.40 and shown in Fig. 2.26. The plutonium disposition mission begins when the first mission fuel is loaded into a reactor in May 2010 and is complete after the last core load, which contains MOX fuel assemblies, has been irradiated for a single cycle in August 2021. The overall reactor mission starts 13.5 years after ROD.

The critical path for this alternative passes through the licensing, design, and facility modifications for the MOX fuel fabrication facility.

2.6.2 Existing LWR Base-Case Cost Summary

Of the $0.95B in investment (up-front) costs for all facilities, the MOX fuel fabrication facility provides the most significant cost contribution at $0.40B. A common set of cost-scaling approaches was used to calculate the LCCs for all existing LWR variants. Figure 2.27 shows the facility investment (up-front) costs graphically and also breaks down the other LCCs. Table 2.41 shows the LCCs for all facilities in the 24-category format. It should be noted that the $433M incentive fee paid to the utility has been broken out separately from its higher level category: O&M and other LCCs. The bottom of Table 2.41 shows the TLCC if the utility incentive fee for the reactor is not included, as was done for the TSR. The investment (up-front) cost for the PWR reactors of $232M includes R&D, licensing, and actual modifications or additions to the existing five PWRs. The investment cost for PuP of $322M is the same as for the other reactor options and is based on a plant capacity of 5 MT plutonium/year.

The recurring cost is largest for the MOX fuel fabrication facility compared with the other facilities. It averages almost $97M/year for the 9.8 years of MOX fuel production operations, not including MOX fuel

Table 2.40. Existing LWR base-case schedule summary

Task name	Duration (years)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Process	3	12/1996	12/1999
PuP Facility	22.8	10/1995	7/2018
RD&D	3	10/1995	9/1998
Oversight, Permitting, and Siting	5	12/1996	12/2001
Design	5.1	12/1996	1/2002
Facility Modification and Preoperation	4.5	1/2002	7/2006
Operation	10	7/2006	7/2016
Decontamination and Decommissioning	2	8/2016	7/2018
MOX Fuel Fabrication Facility	23	4/1996	4/2019
Fuel Qualification	5	4/1996	4/2001
Licensing, Permitting, and Siting	5	12/1997	12/2002
Design	5	12/1996	11/2001
Facility Modification and Preoperation	5	12/2001	12/2006
Fabrication of LUAs	0.5	12/2006	6/2007
Operation	9.8	6/2007	4/2017
Decontamination and Decommissioning	2	4/2017	4/2019
Reactor Facility(-ies)	35.7	12/1998	9/2034
Utility Selection	1	12/1998	12/1999
Licensing	4.2	12/1999	2/2004
Reactor Modifications	4	12/1999	11/2003
Reactor "Ready" to Accept MOX			2/2004
Lead Use Assembly Irradiation	4.5	6/2007	12/2011
MOX Loading Duration	9.8	5/2010	2/2020
Single Irradiation Cycle of Last MOX	1.5	3/2020	8/2021
Spent Fuel Pool Duration	19.8	12/2014	9/2034
HLW Repository Facility			
Licensing	8.5	3/2002	8/2010
Construction	5.5	3/2005	8/2010
MOX Delivery Duration	9.8	12/2024	9/2034

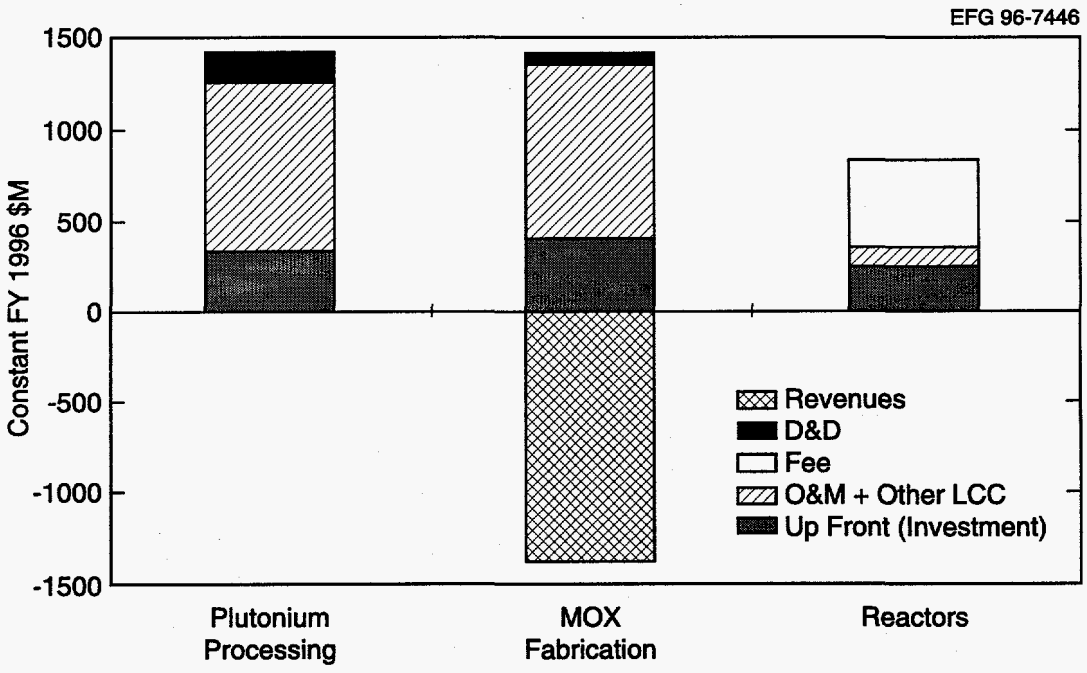


Figure 2.27. LCCs and revenues by facility

Table 2.41. Existing LWR base-case summary LCCs for all facilities in 24-category format

Category	Cost category description	Plutonium processing at SRS and LANL		Government MOX plant in existing building		Five privately owned existing LWRs (government costs)		Repository cost[a]		Total for all facilities
	All costs in constant 1996 $M	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)
	Years of operation	10 years		9.8 years		*b*				
	Preoperational (OPC) up-front costs:									
1	R&D	81		21		36				138
2	NEPA, licensing, permitting	6		35		103				144
3	Conceptual design	3		2		1				6
4	Plans: QA, site qualification, S&S	0		1		2				3
5	Postconstruction startup	50		41		22				113
6	Risk contingency	11		0		0				11
	TOTAL OPC	$151		$100		$164				$415
	Capital (TEC front-end costs):									
7	Title I, II, III engineering, design, and inspection	17		48		10				75
8a	Capital equipment	34		150		0				184
8b	Direct and indirect construction/modification	32		51		58				141
9	Construction management	4		0		0				4
10	Initial spares	3		12		0				15
11	Allowance for indeterminates	25		39		0				64
12	Risk contingency	56		0		0				56
	TOTAL (TEC)	$171		$300		$68				$539
	SUBTOTAL UP-FRONT COST	322		400		232				954
	PuP at LANL (halides)	0		0		0				0
	TOTAL UP-FRONT COST (TPC)	$322		$400		$232				$954

Table 2.41. Existing LWR base-case summary LCCs for all facilities in 24-category format (cont.)

Category	Cost category description	Plutonium processing at SRS and LANL		Government MOX plant in existing building		Five privately owned existing LWRs (government costs)		Repository cost		Total for all facilities
		Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual[c] ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M/year)	Annual ($M)	Lump sum ($M)
	Other LCCs:									
13	O&M staffing	700	70.0	324	33.1	100	7.0			1124
14	Consumables including utilities	85	8.5	321	32.8	0	0			406
15	Major capital replacements or upgrades	0		170	17.3	0	0			170
16	Waste handling and disposal	66	6.6	68	6.9	0	0			134
17	Oversight	10	1.0	10	1.0	0	0			20
18	M&O contractor fees (2% of categories 13–16)	17	1.7	18	1.8	0	0			35
19	Payments-in-lieu-of-taxes to local communities	9	0.9	9	0.9	0	0			18
20	D&D (percent of capital or dollar estimate)	169		60		0	0			229
21	Revenues (if applicable) MOX or electricity	0		−1387	−141.5	0	0			−1387
22a	Revenue from sale of reactor	0		0		0				0
22b	Government fees to privately owned facility	0		0		433	44.2			433
23	Transportation of plutonium forms to facility	35	3.5	26	2.7	26	2.7			87
24	Storage of plutonium at existing 94-1 site facility	0								0
	PuP at LANL (halides)	1	0.1	0		0				1
	TOTAL OTHER LCC	$1092	$92.3	−$381	−$45.0	$559	*d*	0	0	$1270
	GRAND TOTAL ALL LCC	$1414		$19		$791			0	$2224
	GRAND TOTAL WITHOUT FEE[e]	$1414		$19		$358			0	$1791

[a]No incremental costs for the repository
[b]9.8 years for fee and transport; 14.3 years for incremental staff
[c]Maximum receiving costs before revenue total $96.5M/year including transportation.
[d]This annual cost would apply to first 9.8 years only.
[e]The incentive fee was a business-negotiable item not included in the TSR.

sales revenue. Table 2.42 summarizes the staffing for all facilities.

The incremental operating cost (without incentive fee) for the five PWRs is relatively low at only slightly over $9M/year including transportation of MOX fuel to the reactor site. If the fee is included, some years may have recurring costs that surpass $53M/year.

The LCCs for all facilities combined are shown in Fig. 2.28. The total D&D cost of $229M for the PuP and MOX facilities is shown on this chart. The U.S. government is not responsible for any D&D of the private PWR reactors. No repository cost is shown. The utility is already paying the 1-mill/kWh waste fee, and it is assumed that this fee will cover the cost of spent MOX fuel disposal in the same manner it covers spent LEU fuel. The U.S. government will sell MOX fuel to the private utility at the mass-equivalent price of PWR LEU fuel or $1193/kgHM. This amount accounts for the $1.4B fuel displacement credit (revenue from MOX sales) to the U.S. government. Figure 2.29 shows the annual constant-dollar cash flow cost to the U.S. government for this alternative. These costs are somewhat front-end-loaded because of the potential need to complete modification of the five PWRs and the need to modify existing facilities for PuP and MOX fuel production. The effect of the offsetting fuel displacement credit (MOX fuel sales revenue) is also shown. If the net cash flows are discounted at a 5% real discount rate, a total discounted LCC (TDLCC) of $1.3B ($1.1B without fee) results.

Appendix H of this report shows how the LCCs in this chapter relate to those in the July 17, 1996, version of the TSR. Both the Reactor Alternative Summary Report (RASR) LCC and the TSR discounted LCC fall in the lower part of the range for the TDLCCs for the existing LRW alternatives, that is, in the range of $1.0B to $1.6B.

Table 2.42. Staffing summary for existing LWR base case

Facility	Direct staff (FTEs)	Indirect staff (FTEs)	Total staff (FTEs)
PuP	344	555	899
MOX fabrication	110	316	426
Reactor (incremental)	6	6	12
Total	460	877	1337

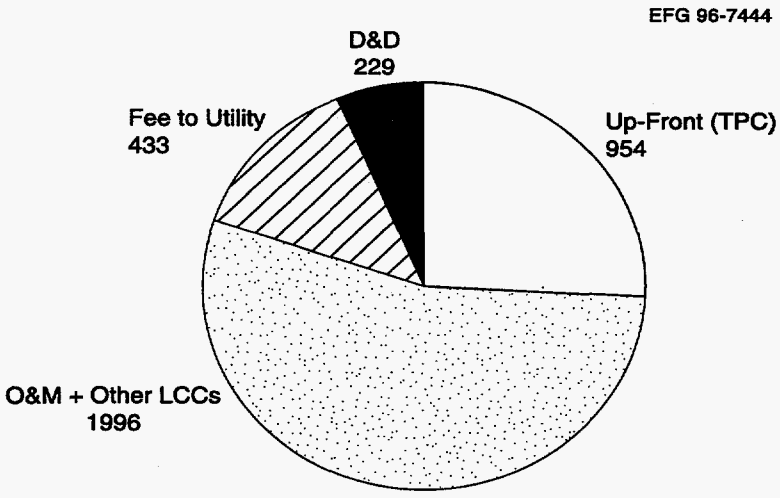


Figure 2.28. Summary of LCCs by major cost category

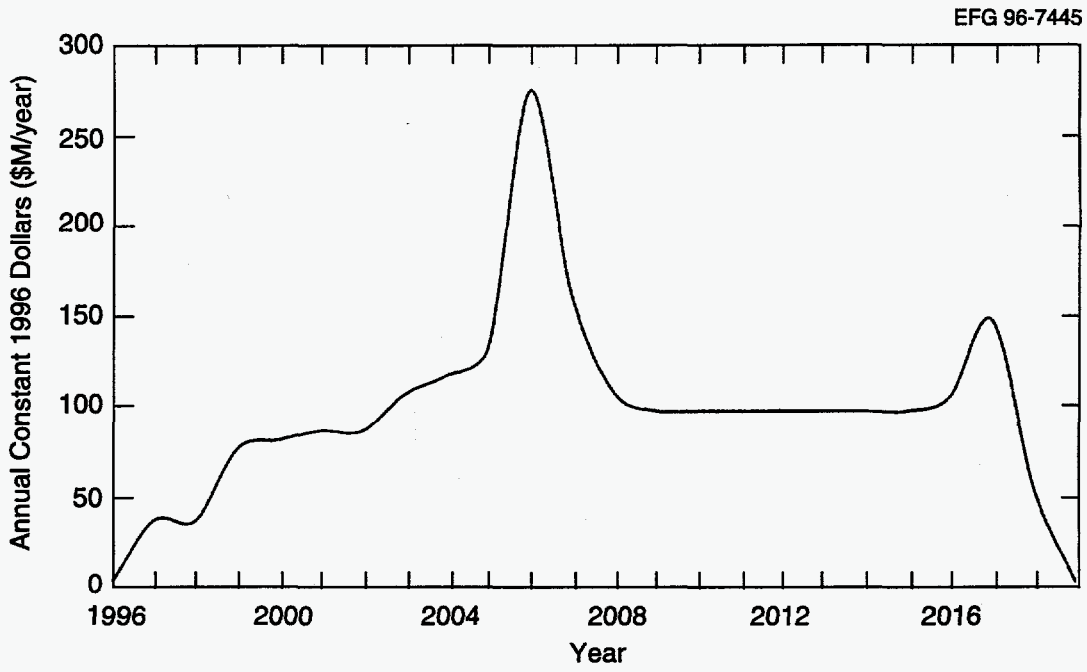


Figure 2.29. Annual constant dollar net cash flow from U.S. government (after MOX sales revenues)

2.6.3 Existing LWR Base-Case S&S Summary

Facilities that handle large quantities of bulk material, have high throughputs, and involve very complex operations have a greater risk that material can be diverted. The plutonium processing and MOX fuel fabrication facilities that are found in this alternative are such facilities. In addition, the material is relatively accessible, and measurement uncertainty may mean that diversion of a significant quantity of material may be more likely. As the material is made into items (e.g., fuel assemblies), the likelihood for diversion decreases. After the fuel has been irradiated, the radiation barriers along with the location and mass of the assemblies make diversion and/or retrieval more difficult.

The SFS means that the material is comparable to existing spent fuel at commercial reactors with respect to its environment, material form, and S&S. The plutonium in MOX spent fuel is as difficult to divert or steal as plutonium in commercial spent fuel. In fact, because MOX fuel originates from weapons material, there is a good chance that this material may have increased visibility with respect to safeguards. *The final disposition form for this alternative meets the spent fuel standard.* Both significant extrinsic (facility) and intrinsic (related to the material form) barriers exist. Because the radiological barrier is time-dependent, this attribute will, over a long period of time, decrease and the material will not be self-protecting. Before the irradiation of the fuel assemblies, the material does not meet the SFS; therefore, protection commensurate with its attractiveness level must be provided.

2.6.4 Existing LWR Base-Case Technical Viability Summary

The PuP facility is the least viable component of the existing LWR alternative. This observation is not a deciding factor in alternative choice because all alternatives must rely on this facility. Though fabrication technology is well known, several issues unique to the plutonium disposition program remain to be resolved. Because the reactor operates with fuel having a fissile fraction similar to that of current uranium-based fuels and because the fuel cycle burnup is similar to existing, extended burnup cycles, viability issues related to the reactor and repository are minor. Furthermore, these issues should be resolvable within the time it takes to construct and license the PuP and MOX fabrication facilities. Consequently, the program mission will not be impacted.

The risk involved with this alternative is primarily from scheduling uncertainty. This, in turn, leads to an

associated economic risk. There is no question that the technologies are feasible. However, the time to implement the technologies is uncertain.

All R&D items are concerned with assessment of fissile material throughput or provision of regulatory certification of the proposed fuel cycle. Throughput items include determination of process reliability and therefore throughput, process optimization to maximize throughput, and cost reduction.

2.7 Reference

1. National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, 1994.

3. Existing LWR Alternative: Private MOX Variant

3.1 Introduction

This existing LWR alternative variant is identical in every way to the base case described in Chap. 2, with the exception that the MOX fuel fabrication facility is privately owned. The important aspect of private ownership is that the government does not have to initially fund the construction of the MOX facility. Instead, it reimburses the owner over the lifetime of the facility for the cost (plus interest) of building and operating the MOX fuel fabrication facility.

3.1.1 Summary Description of Private MOX Variant Disposition Facilities

As stated previously, each facility associated with this variant is identical to the facilities described in Chap. 2, except for the MOX fuel fabrication facility, which is privately owned. This difference will lead only to changes in the MOX-related costs relative to the base case. The schedule for the MOX fuel fabrication facility is identical to the schedule in Chap. 2, Sect. 2.3.6, with the exception of the selection of a private developer for the design and construction of the facility. Refer to Chap. 2 for a detailed description of the facilities. Table 3.1 summarizes the major facilities for this variant.

3.2 PuP Facility

The PuP facility for this variant is identical to the PuP facility for the base case. Refer to Sect. 2.2 for all information on schedule, cost, technical viability, and S&S for the PuP facility.

3.3 MOX Fuel Fabrication Facility

3.3.1 MOX Fuel Fabrication Facility Description

The MOX fuel fabrication facility for this variant is identical to the MOX fuel fabrication facility for the base case except that the facility is privately owned. Refer to Sect. 2.3 for a description of all aspects of the MOX fuel fabrication facility that are not cost related.

3.3.2 MOX Fuel Fabrication Facility Design and Construction

3.3.2.1 MOX Fuel Fabrication Facility Design and Construction Cost

This variant of the five-PWR base case assumes a privately financed and constructed MOX fuel fabrication facility. The facility is the same in size and function as described in Sect. 2.3 for the base case. There are two major differences:

1. A private owner constructs a new Category I building to house the MOX fuel fabrication equipment rather than using an existing government building. This building would be located on a DOE site with a plutonium-handling infrastructure. The private owner would not need to purchase land for the building, and some existing site permits might be usable. The Category I structure adds $50M to the TEC in Table 2.14 and would be distributed among cost categories 7–12, as shown in Table 3.2.

Table 3.1. Summary of major facilities for existing LWR alternative variant using private MOX facility

Reactor type	Number	Ownership of reactor	Ownership of MOX fuel fabrication facility	Collocation of PuP and MOX fuel fabrication facility
PWR	5	Private	Private	No

Table 3.2. Privately owned MOX fuel fabrication facility design and construction costs

Category No.	Cost category description (Private owner's costs)	118 MTHM/year private MOX plant in existing building [lump sum (1996 $M)]
	Capital or TEC part of up-front cost	
7	Engineering, design, and inspection	56
8a	Capital equipment	150
8b	Direct and indirect construction/modification	85
9	Construction management (imbedded in categories 8a and 8b)	0
10	Initial spares	14
11	AFI	45
12	Risk contingency	0
	TOTAL (TEC)	$350

2. For the purpose of calculating LCCs, the government's cost for this phase is zero. The private owner finances and supervises the design and construction of the MOX fuel fabrication facility. The owner's investment costs are recovered in the price of the MOX fuel sold to the government during the 9.8 years the facility operates.

To calculate the price of MOX, a revenue requirements privatization model was used that is similar to the electric utility model described in *Cost Estimating Guidelines for Advanced Nuclear Power Technologies.*[1] This model uses as its input much of the same data used for the government plants (i.e., the TEC, TPC, annual operations cost, D&D cost, and construction duration). In this case the TEC is $350M for the new building and its process equipment, and the TPC, which includes preoperational costs, is $450M. It is assumed that all of these costs will be borne by the private owner and ultimately will be recovered by the sale of MOX fuel. The TPC of $450M represents the "overnight"[a] cost to the owner and does not include interest during construction—commonly called allowance for funds used during construction (AFUDC). (AFUDC is the interest on the construction loan that the private owner needs to take out to plan, design, construct, and start up the facility.) Once the plant is complete, the sum of the overnight cost plus the AFUDC are amortized over the 9.8 years of plant life. The amortization model considers federal and local taxation, depreciation, the nature of the financing (capitalization), and a cost of money and payback pattern that is significantly different from the government's amortization model. Table 3.3 shows the important input parameters in the privatization model and the results as reflected in the price of MOX charged to the government.

The advantage to FMDP of the private financing/ownership option is that FMDP will not need to request funds from Congress for a multihundred-million-dollar line item project. Private financing pushes the government's capital expenditures (capital portion of around $105M/year for the period 2007 to 2016) for the MOX fuel fabrication part of the overall project to the year 2007 and beyond. If the government finances the plant, large expenditures (over $100M/year) would be needed shortly after the year 2000 for design and construction. (See Fig. 2.29.)

3.3.3 MOX Fuel Fabrication Facility Licensing and Permitting

MOX fuel fabrication facility licensing and permitting for the privately owned MOX facility is identical to the base case described in Chap. 2, Sect. 2.3.3.

3.3.3.1 MOX Fuel Fabrication Facility Preoperational Costs

The analysis assumes that the private owner covers all preoperational costs (categories 1–6). These costs are recovered by the owner in the price charged to the government for the MOX fuel. The $100M total in this category is part of the $450M "overnight" cost discussed in Sect. 3.3.2.1. The constituents of this cost are the same as those in Table 2.16 for the base case. At this point in the project life cycle, FMDP has incurred no MOX facility costs.

[a]The term "overnight" cost is a cost estimating term for the cost of a facility that does not include time-dependent interest charges, that is, the total cost if the facility were built in a very short time, hence the term "overnight."

Table 3.3. MOX fuel fabrication facility privatization model inputs and results

Source of money	Financing from each source (%)	Rate (nominal return to investors)
Inputs		
Debt (bonds)	46	0.091
Equity (common stock)	46	0.130
Preferred (preferred stock)	8	0.084
Effective income tax rate	0.38	
Property tax rate	0.02 of capital per year	
Plant economic life	9.8 years	
Decommissioning fund return (real)	0.07	
Construction time	5 years	
Total MOX produced	1158 MTHM	
Overnight cost	$450M	
Annual operations cost	$93.8M/year	
D&D cost	$70M	
Results		
Average cost of money (nominal)	0.1084	
Average cost of money (real)	0.0494	
AFUDC (adds on to $450M overnight cost)	$83M	
Levelized MOX fabrication unit costs needed to provide above returns to private investors/owners	**Cost for 9.8 years ($M/year)**	**Cost of fabricated MOX fuel ($/kg HM)**
Capital investment portion	104.5	884
Operations and recurring costs	93.9	794
Decommissioning cost (sinking fund)	6.4	54
Total	$204.8	$1732

Notes:

1. Nominal financing rates include an assumed 4.1%/year inflation component.
2. A 9.8-year economic life is short compared with the 20+ years for most industrial facilities; thus, the capital portion of the unit cost of MOX is high (it must be depreciated quickly). This constraint is imposed by the fact that this plant is used only for the 50-MT plutonium disposition campaign and will be decontaminated and decommissioned after 9.8 years.
3. The plant overnight, operating, and D&D costs, which are inputs to the model, are assumed to be the same as for a government-owned facility.
4. Using the capital portion ($884/kg HM) of the levelized cost results in this table, a total capital cost of $1023B for 1158 MTHM of MOX is incurred. This compares with $450M for a government-built plant. The difference of $573M is essentially the cost of privatization (i.e., AFUDC, loan amortization, and taxes). The $450M for a government plant essentially includes an imputed AFUDC calculated at the discount rate of 5%. Rather than recovering the capital over the operating life of the plant (as would be done by a government utility issuing special revenue bonds), the government would pay up-front expenses year by year out of the general U.S. Treasury funds as part of the DOE budget. For this reason the government's borrowing costs are lower than for a private owner.
5. The returns to investors shown are more typical of a regulated investor-owned utility than a typical investor-owned manufacturing enterprise because of the lower financial risk associated with a project with a guaranteed product market and hence guaranteed revenues. (The analysis assumes that the MOX plant will sell only to DOE or its utility agent and will not enter the commercial MOX business.)
6. Unless noted, all costs are in constant 1996 dollars.

3.3.4 MOX Fuel Fabrication Facility Operations

Operation of the MOX fuel fabrication facility for the privately owned variant will be identical to the base case variant described in Chap. 2, Sect. 2.3.4. Therefore, all operations processes, schedules, and storage and shipment information are the same as in Chap. 2.

3.3.4.1 MOX Fuel Fabrication Facility Operations Cost

The private owner of the MOX fuel fabrication facility will incur the same types of recurring costs as those incurred by a directly reimbursed contractor of a government-owned contractor-operated (GoCo) facility; therefore, most of the recurring cost data (categories 13–19) shown in Table 2.20 and repeated in the first two columns of Table 3.4 will still apply. [The $2.7M/year in categories 18 and 19 (M&O fees and PILT) may not apply to a private plant; however, corporate overheads not found in government facilities should apply in this case at a similar annual rate.] The $93.8M/year in annual operations costs becomes part of the levelized price of MOX fuel shown in Table 3.3. Transportation costs of $2.7M/year ($PuO_2$ powder from the PuP facility to the MOX fuel fabrication facility and TRU from the fuel fabrication facility to WIPP) are assumed to be a directly contracted government expense not handled by the private owner.

The government payment for MOX fuel at the rate of $1732/kg HM for 1.158 million kg HM (or $205M/year for 9.8 years) is shown in category 22 of the two right-most columns of Table 3.4. This MOX fuel price is high compared with some European quotes ($1200–1700/kg HM); however, European plants have a much longer lifetime during which to recover their capital costs. As with the base case, the government's revenue (or fuel displacement credit) for the sale of MOX fuel to the reactor utility is calculated at the LEU-equivalent rate of $1193/kg HM for the same amount of HM or a revenue rate of $141.5M/year to FMDP over 9.8 years. This revenue appears as category 21 in Table 3.4 and is the same for both a private and government-owned facility.

3.3.5 MOX Fuel Fabrication Facility D&D

The MOX fuel fabrication facility will be constructed for the sole purpose of dispositioning surplus plutonium identified by this program. At the completion of the mission, the MOX fuel fabrication facility will be promptly decontaminated and decommissioned.

3.3.5.1 MOX Fuel Fabrication Facility D&D Cost

The MOX fuel fabrication facility owner covers the projected $70M D&D cost through sinking fund payments into an escrow fund paying 7% interest. These payments are recovered in the price of MOX fuel as is the case for the up-front and operating costs. Of the $1732/kg HM price of MOX fuel, only $54/kg HM is attributable to D&D. The MOX fuel fabrication facility is assumed to have no salvage value to FMDP even after removal of the MOX fuel fabrication equipment, decontamination of the building, and return of the building to a habitable status.

3.3.6 MOX Fuel Fabrication Facility Schedule Summary

The overall privately owned MOX fuel fabrication facility implementation schedule is the same as the schedule for the federally owned MOX fuel fabrication facility discussed in Chap. 2. The only change is the issuing of a request for proposal (RFP) to select a private developer for this facility rather than the selection process for an M&O contractor in the design and construction section of the schedule.

3.3.7 MOX Fuel Fabrication Facility Cost Summary

All nontransportation costs for the MOX fuel fabrication plant are imbedded in the $1732/kgHM price paid by DOE for the privately produced MOX fuel bundles. From the $2007M paid to the private owner, a revenue (fuel displacement credit) of $1387M flows back to DOE from the sale of MOX fuel to the utility at an LEU-equivalent price. With the government transportation costs of $26M, a net LCC of $646M results. This compares with the $19M net LCC for the government ownership case in Chap. 2, which did not include a new building.

3.4 Existing LWR Private MOX Variant Facility

The existing PWR facility for this variant is identical to the base case. Refer to Sect. 2.4 for all information on schedule, cost, S&S, and technical viability for the reactor facility.

Table 3.4. LCCs for five existing LWR privately owned MOX fuel fabrication facility in 24-category format

Category	Cost category description	118.2 MTHM/year private MOX plant in new building operating for 9.8 years			
		Lump sum (1996 $M)	**Annual (1996 $M)**	**Lump sum (1996 $M)**	Annual (1996 $M)
		Private owner's cost		FMDP cost	
	Other LCCs				
	Staff size (total): 426 FTEs (FTEs @ $77,900/year/FTE)				
	Staff size (directs): 110 FTEs				
	Staff size (indirects): 316 FTEs				
13	O&M staffing	324	33.1		
14	Consumables (including utilities)	321	32.8		
15	Major capital replacements or upgrades	170	17.3		
16	Waste handling and disposal	68	6.9		
17	Oversight	10	1.0		
18	M&O contractor fees (2% of categories 13–16)[b]	18	1.8		
19	PILT to local governments (1% of categories 13–16)[b]	9	0.9		
	ACTUAL RECURRING COST SUM FROM PARTITIONING	$920	$93.8		
20	D&D (20% of TEC) sinking fund would provide $70M at end-of-life	70		0	
21	Revenues (if applicable) from sale of MOX or electricity	0[a]		−1387	−141.5
22a	Revenue from sale of reactor				
22b	Fees to privately owned facility (payments for MOX at $1732/kgHM)	0		2007	204.8
23	Transportation of plutonium forms to facility (or T&PT)	0	0	26	2.7
24	Storage of plutonium at existing 94-1 site facility				
	TOTAL OTHER LCC	$990[a]	$93.8	$646[c]	$66.0

[a]Sales revenue to private owner not shown. Only base cost inputs to private owner are considered.
[b]Although a private owner may not need an M&O contractor or require PILT payments, annual corporate overhead amounts may be similar.
[c]Before revenues are included, the FMDP LCC total is $2033M ($2007M + $26M).

3.5 HLW Repository

The HLW repository for this variant is identical to the HLW repository for the base case. Refer to Sect. 2.5 for all information on schedule, cost, S&S, and technical viability for the HLW repository.

3.6 Existing LWR: Private MOX Variant Summary

3.6.1 Existing LWR: Private MOX Variant Schedule Summary

The schedule summary for this variant is identical to the base case. Refer to Chap. 2, Sect. 2.6.1, for the appropriate information.

3.6.2 Existing LWR: Private MOX Variant Cost Summary

3.6.2.1 PuP Facility

The PuP facility LCCs are the same as for the base case.

3.6.2.2 MOX Fuel Fabrication Facility

When the investment, operations, and D&D costs for the MOX fuel fabrication plant are inserted into a privatization model, a unit MOX fuel cost to the government of $1732/kgHM results (Table 3.3). This price includes interest during construction; federal, state, and local property tax; depreciation; zero salvage value for the plant at the end of its life; and all returns to the bondholders (amortization) and stockholders. In summary, the MOX fuel fabrication facility LCC (including revenue and transportation) of $2033M is an increase of more than $567M compared with an equivalent analysis (LCC of $1466M) that assumed government financing had been provided for the project.

3.6.2.3 Reactor Facility

The reactor facility LCCs are the same as in the base case.

3.6.2.4 Summary for All Facilities

Figure 3.1 shows the LCCs and revenues by facility. Table 3.5 shows the same cost data in the 24-category format. The government's payments for privately fabricated MOX fuel ($2007M) exceed the

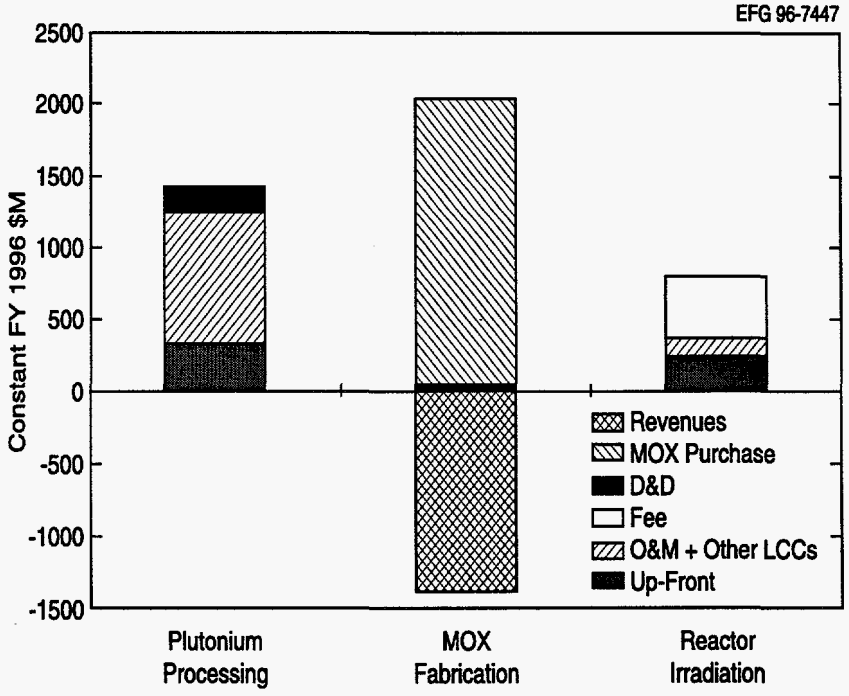


Figure 3.1. LCCs and revenues by facility

Table 3.5. Summary of LCCs for private MOX LWR (five-PWR) variant in 24-category format[a]

Category	Cost category description	PuP at SRS and LANL		Private new MOX plant on fedfield site		Existing reactors		Repository		Total for all facilities [lump sum ($M)]
		Lump sum ($M)	Annual ($M/ year)	Lump sum ($M)	Annual ($/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	
	Years of operation =	10		9.8		9.8 years for fee and transport, 14.3 years for incremental staff				
	Preoperational or OPC up-front costs:							no incremental $ impacts from MOX use		
1	R&D	81				36				117
2	NEPA, licensing, permitting	6				103				109
3	Conceptual design	3				1				4
4	QA, site qualification, S&S plans	0				2				2
5	Postconstruction startup	50				22				72
6	Risk contingency	11				0				11
	SUBTOTAL OPC	$151		0		$164		0		$315
	Capital or TEC front-end costs:									
7	Title I, II, III engineering, design, and inspection	17				10				27
8a	Capital equipment	34				0				34
8b	Direct and indirect construction/modification	32				58				90
9	Construction management	4				0				4
10	Initial spares	3				0				3
11	AFI	25				0				25
12	Risk contingency	56				0				56
	SUBTOTAL (TEC)	$171		0		$68				$239
	SUBTOTAL UP-FRONT COST	$322		0		$232				$554
	PuP at LANL (halides)	0		0		0				0
	TOTAL UP-FRONT COST (TPC)	$322		0		$232		0		$554

Table 3.5. Summary of LCCs for private MOX LWR (five-PWR) variant in 24-category format[a] (cont.)

Category	Cost category description	PuP at SRS and LANL		Private new MOX plant		Existing reactors		Repository		Total for all facilities [lump sum ($M)]
		Lump sum ($M)	Annual ($M/ year)	Lump sum ($M)	Annual ($/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	
	Other LCCs:									
13	Operations and maintenance staffing	700	70.0	0		100	7.0			800
14	Consumables including utilities	85	8.5	0			0			85
15	Major capital replacements or upgrades	0		0			0			0
16	Waste handling and disposal	66	6.6	0			0			66
17	Oversight	10	1.0	0			0			10
18	M&O contractor fees	17	1.7	0			0			17
19	PILT to local communities	9	0.9	0			0			9
										0
20	D&D	169				0				169
21	Revenues (if applicable) MOX or electricity	0		−1387	−141.6	0				−1387
22	Fees to privately owned facilities (reactor and MOX)	0		2007	204.8	433	44.1			2440
23	Transportation of plutonium forms to facility	35	3.5	26	2.7	26	2.7			87
24	Storage of plutonium at existing 94-1 site facility									0
	PuP at LANL (halides)	1	0.1	0		0				1
	TOTAL OTHER LCC	$1092	$92.3	$646	$66.0	$559	*b*	0		$2297
	GRAND TOTAL ALL LCCs	$1414		$646		$791		0		$2851
	GRAND TOTAL LCC WITHOUT FEE[c]	$1414		$646		$358		0		$2418

[a] All costs are in constant 1996 $M.

[b] Not the same every year; therefore, no recurring cost is shown.

[c] The TSR did not include an incentive fee.

LEU-equivalent revenues received ($1387M) by $620M. If the new MOX plant were government built and owned, the payments would exceed revenues by $69M. The combined LCCs for all facilities are shown in Fig. 3.2. Figure 3.3 shows the annual constant dollar cash flow from the U.S. government for this

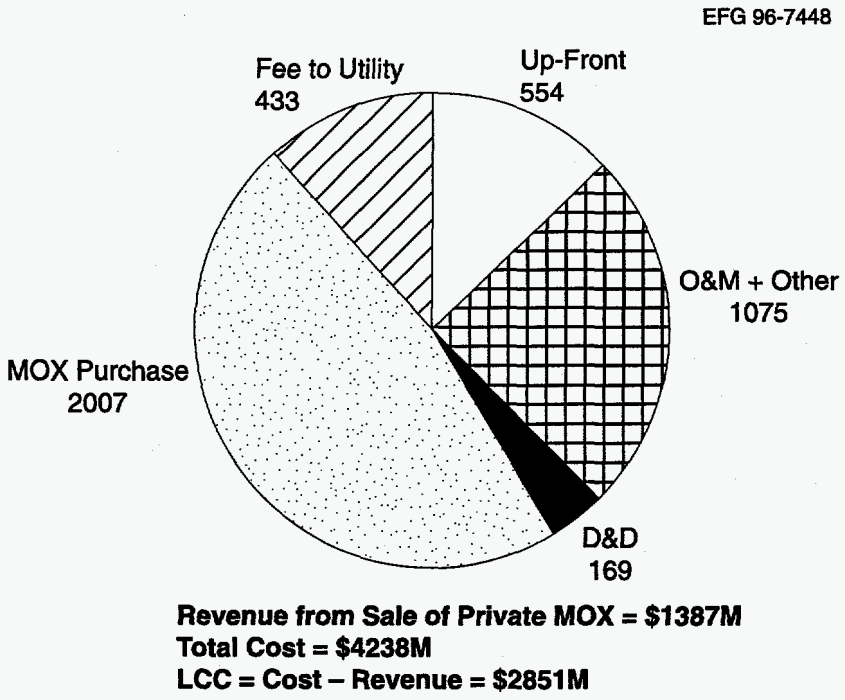


Figure 3.2. Summary of LCCs by major cost category

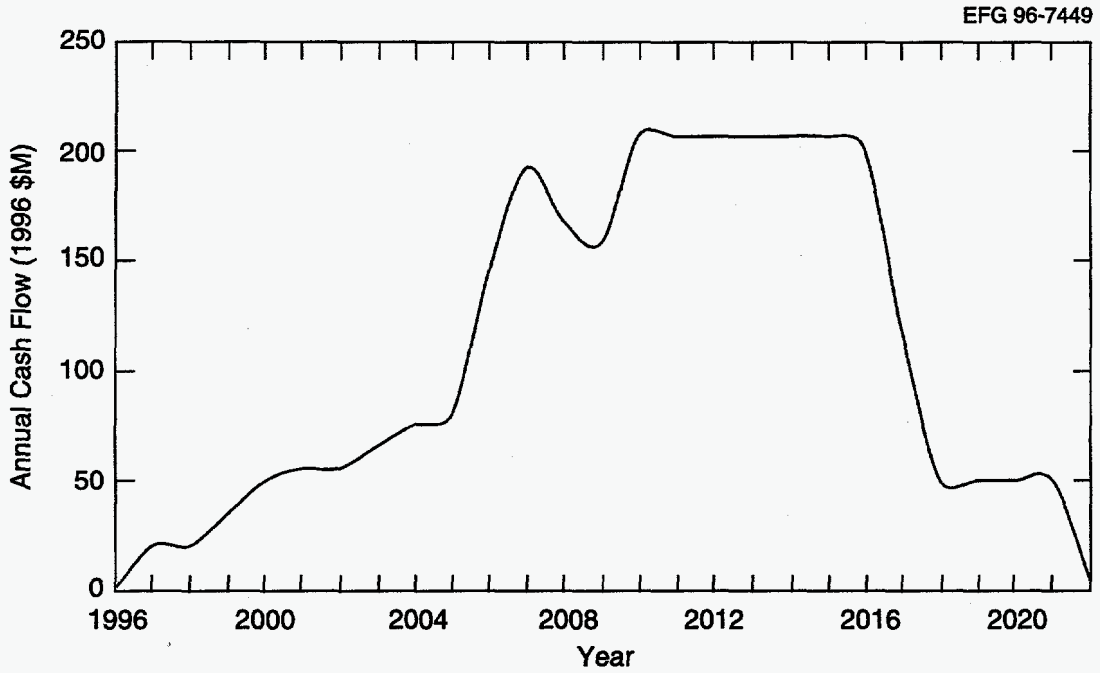


Figure 3.3. Annual constant dollar net cash flow from the U.S. government (after MOX sales revenues)

alternative. If the net cash flows are discounted at a 5% real discount rate, a TDLCC of $1.46B results. Staffing for this alternative is anticipated to be the same as for the existing LWR base case (Chap. 2) if the staff of the private MOX plant is counted. (See Table 2.42.)

The relationship of the LCCs discussed in this chapter to those discussed in the July 17, 1996, TSR is discussed in Appendix H, Sect. H.3.

3.6.3 Existing LWR: Private MOX Variant S&S Summary

The S&S summary for this variant is identical to the S&S for the base case. Refer to Sect. 2.6.3 for information on S&S.

3.6.4 Existing LWR: Private MOX Variant Technical Viability Summary

Technical viability issues of this variant are identical to those of the base-case existing LWR alternative (Chap. 2), except as noted in Appendix E.

3.6.5 Existing LWR: Private MOX Variant Transportation Summary

The transportation aspects of this case are identical to those for the existing LWR base case. See Sect. 2.6.5 for more information.

3.7 Reference

1. J. G. Delene and C. R. Hudson II, *Cost Estimating Guidelines for Advanced Nuclear Power Technologies*, ORNL/TM-10071/R3, Oak Ridge National Laboratory, May 1993.

4. Existing LWR Alternative: Four-BWR Variant with Collocated PuP/MOX Facility

4.1 Introduction

The existing LWR alternative that uses BWRs with collocated PuP/MOX facilities is a specific form of the generic reactor alternative (Fig. 1.2) in which four existing, privately owned BWRs are employed to irradiate the MOX fuel. For this chapter, existing LWRs are defined as large BWRs with operating licenses that extend to mission completion. The mission is complete for this alternative after the first irradiation cycle of the last core load that contains MOX fuel assemblies.

As in the base case, the PuP facility would be government-owned, and located on an existing federal site. It would operate for ~10 years. In this variant, the PuP facility would be collocated with the MOX fuel fabrication facility within one PIDAS fence. The two facility buildings would both be new, and can, but do not have to be, attached. Because of the different amount and type of MOX fuel that must be produced to supply four BWRs (instead of the five PWRs in the base case), the MOX facility may be slightly smaller than the MOX facility needed in the base case but would have to operate longer. Table 4.1 shows the proposed ownership of the facilities that would be considered for further analysis if this alternative is chosen at ROD.

Table 4.1. BWR alternative—collocated PuP/MOX facility

Reactor type	Number	Ownership of reactor	Ownership of collocated PuP/MOX facility
GE BWR-5	4	Private	Federal

As in the base case, the power rating of the reactor chosen for the plutonium disposition mission, coupled with the reactor core design and the burnup, establishes the plutonium throughput for the reactors. This value, in turn, establishes the throughput for all private operations.

The top-level diagram, Fig. 4.1, shows the four major operations in this alternative: PuP and MOX fuel fabrication facilities collocated at one facility, reactor facility, and HLW repository. The diagram shows the plutonium flow through the four major operations.

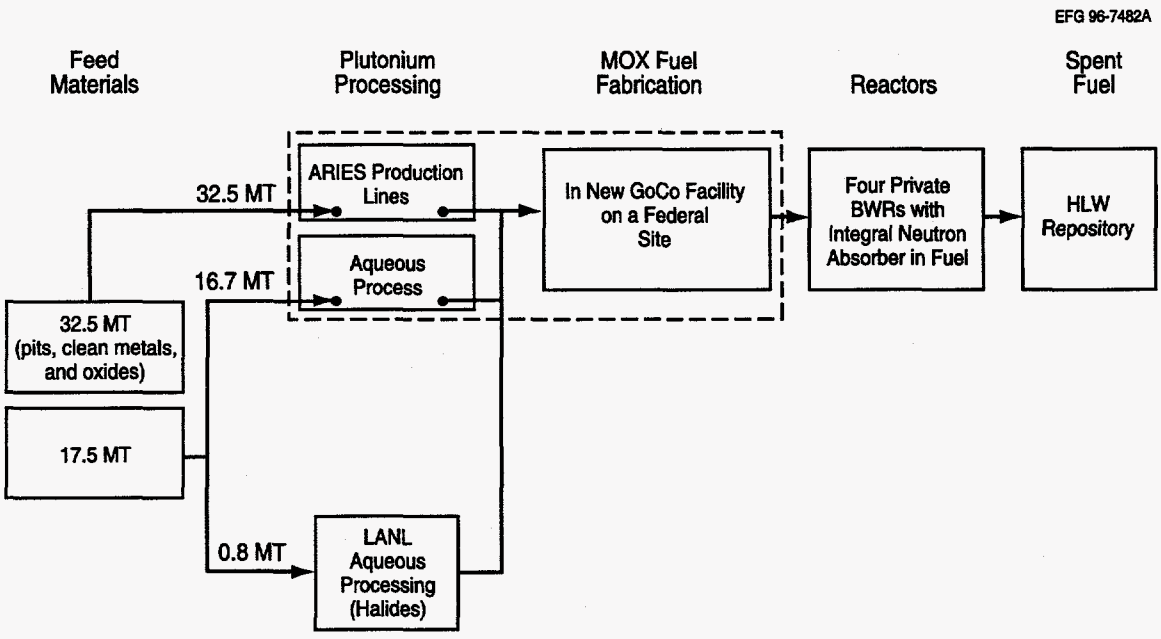


Figure 4.1. Top-level flow diagram for the existing four-BWR alternative (collocated PuP/MOX facilities)

4.1.1 General Assumptions

The assumptions made for this variant are the same as the assumptions made for the base-case existing LWR alternative in Sect. 2.1.1.

4.1.2 Summary Description of Four-BWR Variant Disposition Facilities

The following facilities are included in this alternative:

PuP/MOX Facility—It is assumed that the baseline PuP/MOX facility is constructed at an existing federal site. The plutonium pits and clean metal (~32.5 MT of plutonium) would be processed by the ARIES HYDOX dry processing procedure, and the other feed material (~17.5 MT of plutonium) would be processed by an aqueous procedure. A small amount of halide-contaminated plutonium is assumed to be processed at available facilities at LANL. The end product of the PuP facility is PuO_2 that meets the specifications for feed to the MOX fuel fabrication portion of the facility. PuO_2 from the PuP portion of the collocated facility is required to fabricate MOX fuel for use in the reactors. The PuP facility will be subject to external review by the DNFSB.

The MOX fuel fabrication portion of the new collocated facility will be used for receiving the oxide, rod and bundle components, depleted UO_2 neutron absorber, and additives for fabrication of MOX fuel; assembling fuel bundles; and shipping the fuel to the BWRs. Full MOX fuel assemblies are assumed to contain 3 wt % plutonium in HM. It is assumed that any gallium will be substantially removed before the powder is blended to make MOX fuel. This portion of the facility will be licensed by the Nuclear Regulatory Commission (NRC).

BWRs—Four 3484-MW(t) [1165-MW(e)] BWR-5 reactors with full MOX cores will irradiate the MOX fuel for its economic life during which the MOX fuel will be transformed to meet the SFS. These reactors are assumed to operate at a capacity factor of 80%. For the purpose of this analysis, the reactors were assumed to be located at two dual unit sites in the midwest.

HLW Repository—The HLW repository will be used for receiving the spent fuel in large canisters, transferring the sealed canisters to disposal casks, and moving the casks underground for emplacement. The HLW repository is included here for completeness because the spent fuel will ultimately be emplaced in a geologic repository. Emplacement in a geologic repository, however, is not required to achieve the SFS.

It is imperative that each facility provide acceptable material to the follow-on facility in a timely manner to meet the desired mission schedule. After cooling for 10 years in the spent fuel pool at the reactor facility, spent fuel is then sent to the HLW repository.

Figure 4.2 shows the proposed production schedule for the MOX fuel as well as the fuel-loading schedule for the reactors. Figure 4.3 shows the MOX fuel assembly schedule, fuel-loading schedule, and the schedule for sending spent fuel to the repository. Additional detail is provided on the individual facilities in the remainder of this chapter.

4.1.3 Description of Facility Interfaces for the Four-BWR Variant Disposition

As discussed in Chap. 2, multiple facilities are required for disposition of ~50 MT of excess weapons-usable plutonium as MOX fuel in existing LWRs. For the four-BWR variant, these are the same facilities and material flows discussed in Sect. 2.1.2, with the exception that the PuP facility and MOX facility are located behind one PIDAS fence. Figure 4.4 provides a simplified flowchart of the transportation segments associated with this variant. PuO_2 repackaging and SST shipments may be required to move the feed material from the PuP portion of the collocated facility to the MOX portion of the facility.

4.2 Collocated PuP/MOX Facility

4.2.1 Collocated PuP/MOX Facility Description

The PuP facility for this alternative will be collocated with the MOX facility at an existing federal site. The size, processes, and functions of the PuP facility are the same as those described in Sect. 2.2.1. For transportation analysis purposes, a western federal site was used.

The size, processes, and functions of the MOX facility are the same as those described in Sect. 2.3.1. However, the MOX fuel fabrication facility will be designed to supply 602 fuel assemblies/year of BWR fuel to the four reactors and would operate for a total

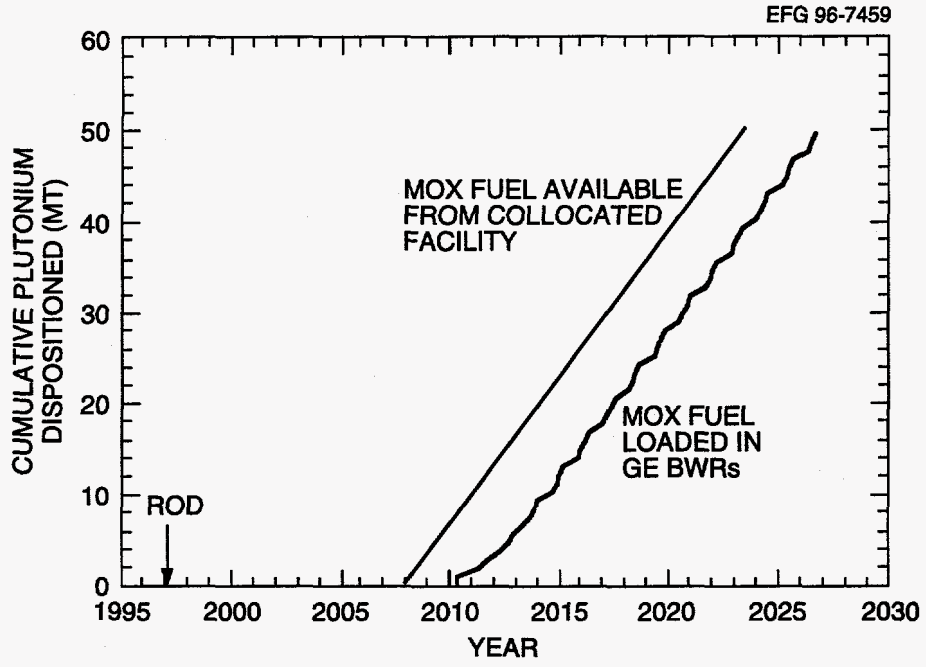


Figure 4.2. Plutonium disposition schedule

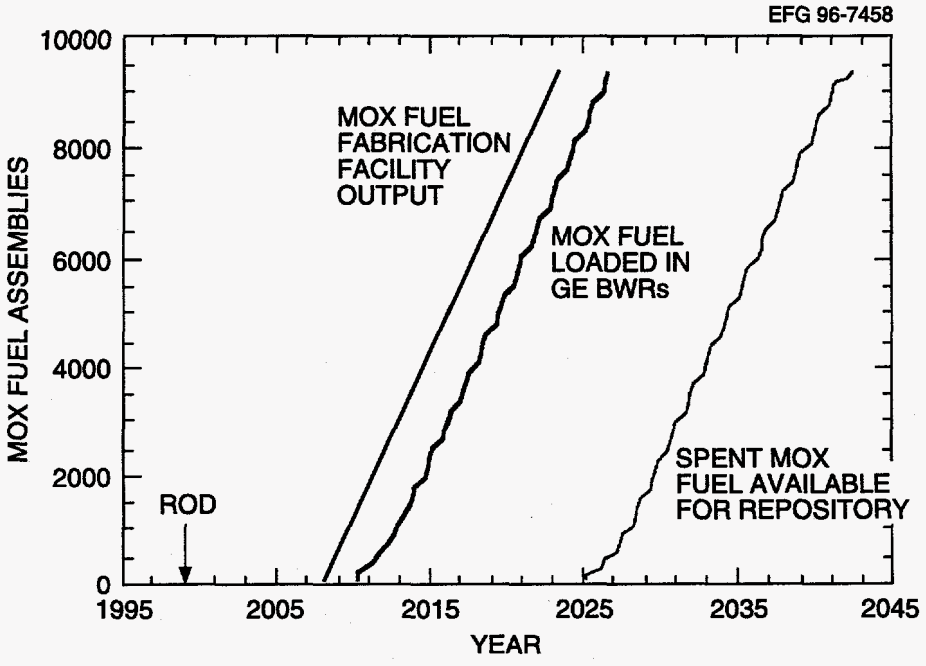


Figure 4.3. Schedule for MOX fuel assembly processing, fuel loading, and availability of spent fuel for the repository

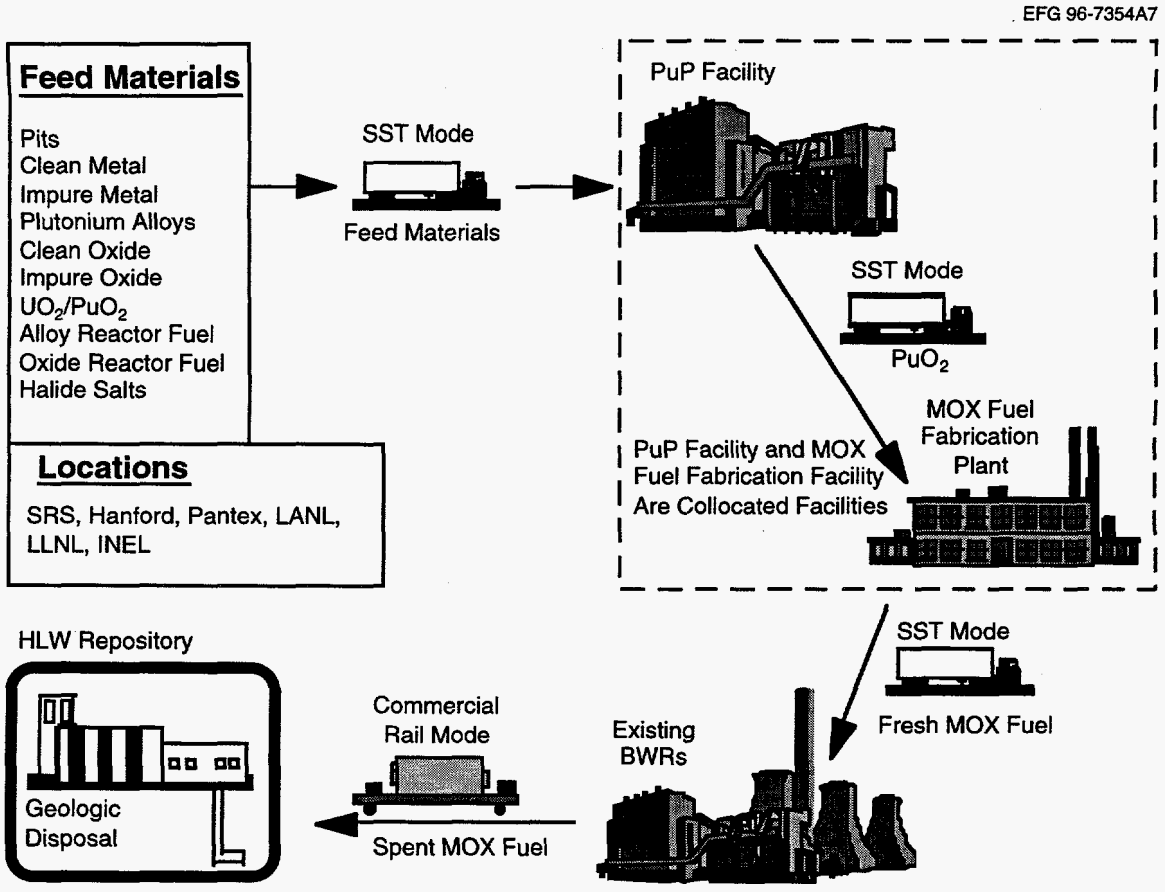


Figure 4.4. Transportation segments for the existing LWR four-BWR alternative

of 187 months (15.6 years), as opposed to the 124 months for the base case. Table 4.2 provides the MOX facility batch process data.

4.2.2 Collocated PuP/MOX Facility Design and Construction

The duration and path of the design and construction tasks for the collocated PuP and MOX fuel fabrication facilities are based on a generic DOE Major System Acquisition—Capital Construction Project. For the PuP facility, design and construction will begin at ROD with the selection of the AE firm, as in Sect. 2.2.2.1. Conceptual design will also start the NRC licensing process for the MOX fabrication facility as described in Sect. 2.3.2.1.

Research, development, and demonstration (RD&D) of the various PuP technologies are currently under way. The prototype phase of ARIES is scheduled to begin in 1998. The fuel qualification demonstration is currently under way and is scheduled to be completed in 2001.

4.2.2.1 Collocated PuP/MOX Fuel Fabrication Facility Design and Construction Schedule

The design and construction tasks for the collocated PuP and MOX fuel fabrication facilities are a combination of the design and construction schedules for the two separate facilities discussed in Chap. 2. The 1-year site selection process to determine the most appropriate federal site for the collocated facility will start 1 year after ROD. The selection process for the M&O contractor will start after the intermediate approval for line item funding. This contractor will be responsible for developing the Title I and II designs and for constructing the new facility. Work on Title II starts after approval of the Title I design and the final line item funding. The site preparation and equipment procurement starts after completion of Title II design and up to 1 year before the completion of the NRC licensing process; however, no safety-related construction may be done until after the license has been granted. The design and construction schedule is shown in Table 4.3 and as a part of Sect. 4.2.6.

Table 4.2. Collocated MOX fuel fabrication facility batch process data

Process	Process cycle data[a]	Data (average)
Receiving and storage	Plutonium throughput Cycle time Plutonium input form Plutonium output form	266 kg 1 month PuO_2 PuO_2
MOX fuel fabrication	Plutonium throughput Cycle time Plutonium input form Plutonium output form	3197 kg 1 year PuO_2 MOX fuel assemblies
Bundle shipping	Plutonium throughput Cycle time Plutonium input form Plutonium output form	602 bundles 5.31 kg per assemblies 1 year MOX fuel assemblies MOX fuel assemblies

[a]Plutonium throughput represents amount of PuO_2 received in a single shipment. Cycle time represents interval between expected shipments of PuO_2.

Table 4.3. Collocated PuP/MOX fuel fabrication facility design and construction schedule

Task name	Duration (months)	Start	Finish
R&D Funding Available			10/1995
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Fuel Qualification Demonstration	60	4/1996	4/2001
Research & Development	36	10/1995	10/1998
Site Selection	12	12/1997	12/1998
M&O Contractor Selection	12	12/1998	12/1999
Design Process	60	12/1996	12/2001
Conceptual Design	25	12/1996	1/1999
Title I	12	12/1999	12/2000
Title II	12	12/2000	12/2001
Facility Construction	53	1/2002	6/2006
Construction	53	1/2002	6/2006
Procurement	36	1/2002	1/2005
Equipment Installation	17	1/2005	6/2006

4.2.2.2 Collocated PuP/MOX Facility Design and Construction Cost

The cost estimate for this facility is a combination of two different estimates, as shown in Table 4.4. Design and construction are part of the total estimated cost or TEC (categories 7–12 in Table 4.4). The MOX portion of the collocated plant estimate was prepared as discussed in Sect. 2.3. The differences from the Sect. 2.3 base case consist of an additional $50M for a new Category I building and a MOX fuel throughput of 98.8 MTHM/year (for four BWRs). A TEC of $350M was estimated for the new government-owned MOX fuel portion of the facility. The TEC obtained for the add-on or nearby PuP facility was $385M, which when added to the MOX fuel fabrication facility, gives a TEC of $735M for the collocated facility. The right-hand column of Table 4.4 shows the TECs by category for the total plant.

4.2.3 Collocated PuP/MOX Facility Oversight and Permitting

The licensing approach for this reactor-based plutonium disposition variant is the same as discussed in Chap. 2, Sects. 2.2.3 and 2.3.3.

4.2.3.1 Collocated PuP/MOX Fuel Fabrication Facility Licensing and Permitting Schedule

For this analysis, it has been assumed that the duration of the NRC licensing process will be 5 years and that the process will start 1 year before the conceptual design is complete. The NEPA process and the other site-specific permitting will require 3 years; each process will start after the site has been selected. The licensing schedule is shown in Table 4.5 and as a part of Sect. 4.2.6.

4.2.3.2 Collocated PuP/MOX Operations-Funded Project Cost

The OPC for the collocated facility is the sum of the two different OPC estimates shown in Table 4.4. The NEPA, licensing, and permitting portion of the OPC estimate is $70M. All OPCs total to $315M.

4.2.4 Collocated PuP/MOX Operations

This case is the only reactor variant for which a new facility is considered for both plutonium processing and MOX fuel fabrication. It is also the only variant where a cofunctional, collocated PuP/MOX fuel fabrication facility is considered (i.e., both prereactor plutonium-handling functions are performed in one facility). It does share with the other reactor options the fact that the new collocated facility is located on a "fedfield" site (i.e., a site that has an existing plutonium-handling infrastructure such as waste handling, a trained security force, existing permits, and analytical laboratory capabilities).

4.2.4.1 Collocated PuP/MOX Fuel Fabrication Facility Operations Schedule

The preoperational checkout of the collocated PuP/MOX fuel fabrication facility will start 1 year before the equipment installation is complete and will take 2 years. The PuP section of the facility will operate for 10 years with an annual throughput of 5 MT. The LUAs will be ready for loading into the first reactor 6 months after the start of operations at the facility. Following this startup period, the MOX fuel fabrication section of the facility will operate for 15.6 years with an annual plutonium throughput rate of 3.2 MT. This throughput assumes an annual output of 602 assemblies for a mission total of 9416 assemblies and will supply fuel for the four existing BWRs at the specified loading rate. The operational schedule is shown in Table 4.6 and as a part of Sect. 4.2.6.

4.2.4.2 Collocated PuP/MOX Operations Cost

The PuP portion of the collocated facility is assumed to operate for 10 years to produce clean PuO_2 feed for the MOX portion of the plant. Because the MOX portion of the facility runs for 15.6 years, space must be included for the storage of PuO_2 powder. The right-hand column of Table 4.4 shows the total operation costs when the two portions of the collocated facility are operating concurrently (i.e., the first 10 years).

Table 4.7 shows the staffing levels needed for collocated facility operations and compares this staffing level with that needed for separate PuP and MOX fuel fabrication facilities. (Because of the reduced annual plutonium throughput, these separate facilities would be somewhat smaller than the facilities described in Chap. 2.) The analysis shows that separate PuP and MOX facilities require 517 additional staff. The total annual operations cost (recurring cost plus transportation) for the collocated facility is $149M/year compared to $176M/year for separate facilities, a savings of $27M/year. Transportation costs assume that SSTs are used to move PuO_2 between buildings (if necessary) (Fig. 4.4).

Table 4.4. LCCs for collocated PuP/MOX facility

Category	Cost category description	PuP portion of collocated plant (new building)		MOX fuel fabrication portion of collocated plant (new building)		Total for collocated PuP/MOX facility	
		Lump sum ($M)[a]	Annual ($M/year)[a]	Lump sum ($M)[a]	Annual ($M/year)[a]	Lump sum ($M)[a]	Annual ($M/year)[a]
	10 years of operation for PuP; 15.6 years of operation for MOX fabrication						
	Plant capacity (5 MT plutonium/year for PuP; 98.8 MTHM/ year for MOX)						
	Estimating basis:	Plutonium post-processing model		LANL/ORNL algorithms			
	Preoperational or OPC up-front costs:						
1	R&D	89		21		110	
2	NEPA, licensing, and permitting	35		35		70	
3	Conceptual design	7		2		9	
4	Q/A, site qualification, and S&S plans	5		1		6	
5	Postconstruction startup	45		41		86	
6	Risk contingency	34		0		34	
	TOTAL OPC	$215		$100		$315	
	Capital or TEC front-end costs:						
7	Title I, II, III engineering, design, and inspection	29		56		85	
8a	Capital equipment	190		175		365	
8b	Direct and indirect construction/modification	70		60		130	
9	Construction management	16		0		16	
10	Initial spares	4		14		18	
11	AFI	76		45		121	
12	Risk contingency	0		0		0	
	TOTAL TEC	$385		$350		$735	
	SUBTOTAL UP-FRONT COST	$600		$450		$1,050	
	PuP at LANL (halides)	$0		$0		$0	
	TOTAL UP-FRONT (INVESTMENT) COST (TPC)	$600		$450		$1,050	

Table 4.4. LCCs for collocated PuP/MOX facility (cont.)

Category	Cost category description	PuP portion of collocated plant (new building)		MOX fuel fabrication portion of collocated plant (new building)		Total for collocated PuP/MOX facility	
		Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)
	Other LCCs:						
13	Operations and maintenance staffing	297	29.7	471	30.2	768	59.9
14	Consumables including utilities	83	8.3	432	27.7	515	36.0
15	Major capital replacements or upgrades	127	12.7	237	15.2	364	27.9
16	Waste handling and disposal	69	6.9	90	5.8	159	12.7
17	Oversight	10	1.0	16	1.0	26	2.0
18	M&O contractor fees (2% of categories 13–16)	12	1.2	25	1.6	37	2.8
19	PILT to local communities (1%)	6	0.6	12	0.8	18	1.4
	TOTAL RECURRING COST (ANNUAL)		$60.4		$82.3		$142.7
20	D&D (percentage of capital or dollar estimate)	386		70		456	
21	Revenues (if applicable) MOX or electricity	0		–2006	–128.6	–2006	–128.6
22	Fees to privately owned facility	0		0		0	
23	Transportation of plutonium forms to facility	50	5.0	26	1.7	76	6.7
24	Storage of plutonium at existing 94-1 site facility	0				0	
	Plutonium processing at LANL (halides)	1	0.1	0		1	
	TOTAL OTHER LCC (Annual costs are summed without MOX revenues)	$1041	$65.5	–$627[b]	$84.0[c]	$414[b]	$149.5[c]
	GRAND TOTAL ALL LCC	$1641		–$177		$1464	

[a]All costs are in constant 1996 $M.

[b]Collocated facility other LCCs are $2420M before revenues; MOX other LCCs are $1379M before revenues.

[c]Net annual costs including revenues would be –$44.6M/year for the MOX facility and $20.9M/year for the entire collocated PuP/MOX facility.

Table 4.5. PuP/MOX fuel fabrication facility licensing and permitting schedule

Task name	Duration (months)	Start	Finish
Licensing and Permitting	60	1/1998	1/2003
NRC Licensing	60	1/1998	1/2003
Environmental/NEPA/DOE	36	12/1998	11/2001
Permitting	36	12/1998	11/2001

Table 4.6. Collocated PuP/MOX fuel fabrication facility operational schedule

Task name	Duration (months)	Start	Finish
Preoperational Phase	24	6/2005	6/2007
Operation	193	6/2007	7/2023
Facility Operation Start			6/2007
LUA Fabrication	6	6/2007	12/2007
PuP Operation	120	6/2007	6/2017
MOX Operation	187	12/2007	7/2023

Table 4.7. Staffing levels for collocated, cofunctional PuP/MOX facilities vs staffing levels for separate facilities

Facility	Direct (FTEs)	Indirect (FTEs)	Total (FTEs)
Collocated, cofunctional facility			
Fedfield plutonium processing activity	96	286	382
MOX fuel fabrication facility activity	100	288	388
TOTAL	196	574	770
Separate facilities (PuP in existing SRS 221-F building, MOX at separate site)			
Plutonium processing	344	555	899
MOX fuel fabrication facility	100	288	388
TOTAL	444	843	1287

Before MOX sales revenues, other LCCs (operations and D&D) total $2.4B. Revenue of $128.6M/year ($2006M total for ~1.6 million kg of BWR MOX fuel) is anticipated from selling MOX fuel to the BWR utility. This revenue is based on selling the MOX fuel at a BWR LEU price of $1214/kg HM. [Note: BWR fuel is slightly more expensive to fabricate than PWR fuel ($1139/kgHM).] After revenues, the other LCCs for this facility total $414M.

4.2.5 Collocated PuP/MOX Facility D&D

4.2.5.1 Collocated PuP/MOX Facility D&D Schedule

The duration for the D&D of the facility is estimated to be 2 years (Table 4.8).

4.2.5.2 Collocated PuP/MOX Facility D&D Cost

D&D for the collocated facilities may cost more than D&D of separate facilities because the D&D cost for the existing PuP facility may be shared with another SRS program. The cost estimate for the collocated facility is a combination of the two different estimates shown in category 20 of Table 4.4. The total D&D estimate is $456M.

4.2.6 Collocated PuP/MOX Facility Schedule Summary

The overall collocated PuP/MOX fuel fabrication facility implementation schedule is summarized in Table 4.8 and shown in Fig. 4.5. This facility schedule is also discussed as part of the overall alternative schedule in Sect. 4.5.1. This schedule does not include any contingency for schedule slip caused by site selection difficulties, redesign, construction delays, or a delay in the approval of line item funding.

Critical to the development of this facility is the conceptual design and the NRC licensing process that must take place before construction may begin. If either of these tasks slip in their schedule, the rest of the implementation process will also be delayed. This critical path is shown in Fig. 4.5.

4.2.7 Collocated PuP/MOX Facility Cost Summary

Table 4.4 shows the total LCC for the collocated PuP/MOX facility. Before the fuel displacement credit of $2006M, the facility LCC is $3.47B. After this credit, the net LCC is $1.46B.

Table 4.8. Collocated PuP/MOX fuel fabrication facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Fuel Qualification Demonstration	60	4/1996	4/2001
Site and Facility Selection	12	12/1997	12/1998
Select M&O Contractor	12	12/1998	12/1999
Licensing and Permitting	60	1/1998	1/2003
Design Process	60	12/1996	12/2001
Facility Construction	53	1/2002	6/2006
Preoperational Phase	24	6/2005	6/2007
LUA Fabrication	6	6/2007	12/2007
PuP Operation	120	6/2007	6/2017
MOX Fabrication Operation Duration	187	12/2007	7/2023
D&D	24	7/2023	7/2025

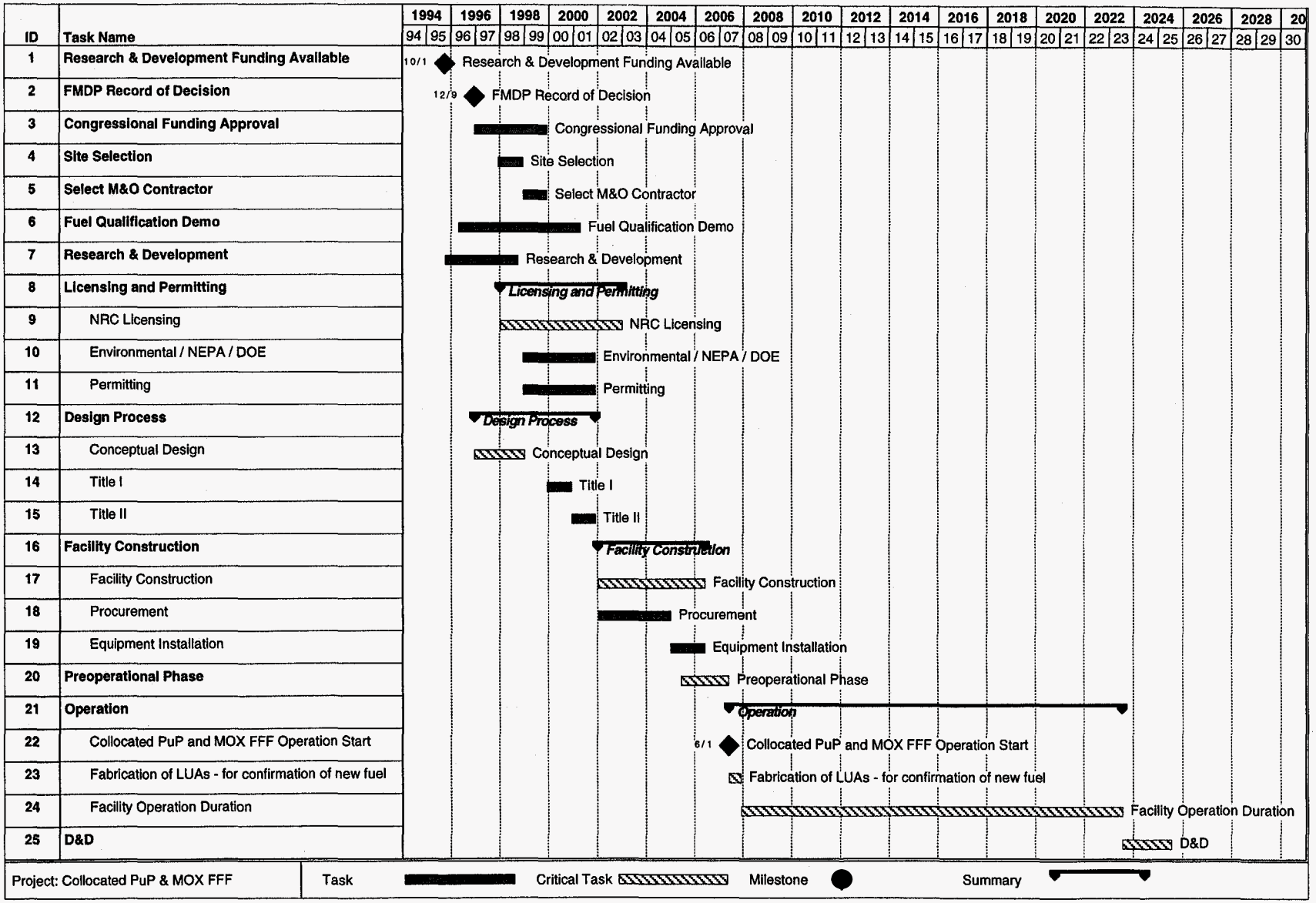


Figure 4.5. Collocated PuP/MOX fuel fabrication facility schedule summary

4.2.8 Collocated PuP/MOX Facility S&S Summary

Collocated facilities should decrease the S&S risks because of fewer handling and transport steps. A single facility for plutonium processing and MOX fuel fabrication will exist; hence, S&S measures could be consolidated, reducing the costs in this area. Within the facility, differences in process steps will need to be analyzed for any differences from the existing LWR base case. The decrease in the shipping and receiving steps for the collocated facility reduces the opportunity for theft and diversion. The decrease in intersite transportation reduces the overall risk for this alternative. Table 4.9 provides information about the material flow of plutonium through this facility and a description of the material and its attractiveness level.

4.2.9 Collocated PuP/MOX Facility Technical Viability Summary

Technical viability issues for the PuP/MOX facility of this variant are identical to those of the existing LWR base case (Chap. 2) for the combined PuP facility (Sect. 2.2.9) and MOX fuel fabrication facility (Sect. 2.3.9) except for issues related to integral burnable neutron absorbers.

4.3 Four-BWR Facility

The existing BWR facility receives MOX fuel from the MOX fuel fabrication facility containing surplus plutonium and irradiates it to achieve the SFS.

As shown in Fig. 1.3, operating license extensions would be required in order for GE plants to complete the one cycle irradiation of the last assembly (12/2027) analyzed in this variant unless more than four BWRs are used to complete the mission. Innovative core designs are being developed that could shorten the reactor portion of the disposition project to allow the use of BWRs.

4.3.1 Four-BWR Facility Description

Technical Maturity—As noted in Chap. 2, judging the maturity of the technologies employed in plutonium disposition facilities requires an assessment of the current level of development of each stage of the fuel cycle. MOX fuel fabrication is a well-developed technology; however, the addition of integral burnable neutron absorbers to the fuel fabrication process is in the conceptual stage and has associated risk issues and R&D needs.

Technical Risks—Certain technologies have associated technical unknowns. Consequently, risks are associated with the application of the technologies based on these unknowns.

A new technology for MOX fuel is the addition of integral burnable neutron absorbers to the fuel. Specific technical issues that must be resolved include acceptable integral burnable neutron absorber distribution within the fuel, and acceptable chemical interactions with the fuel and/or clad.

The risks associated with these technical unknowns are the same as those identified in Chap. 2. Unacceptable fuel production will delay the disposition of plutonium and jeopardize achievement of program goals. Considering the current level of technical development, the degree of risk associated with the MOX fuel fabrication process is thought to be low.

R&D Needs—As noted in Chap. 2, various parameters are identified as unknown or poorly known. The one parameter associated with this variant that needs to be addressed, in addition to those identified for the base case, is the issue of integral burnable neutron absorbers.

Integral Burnable Neutron Absorber Impact—R&D is required to develop and demonstrate the processes required for adding burnable neutron absorbers to the fuel.

Fuel Component Homogeneity—Introduction of burnable neutron absorbers into the fuel matrix has been proposed for the BWR variant. Consequently, pellets manufactured in this manner must be tested to ensure homogeneous distribution of both the PuO_2 and burnable neutron absorber throughout the fuel matrix. Although statistically based destructive testing could be used, R&D is proposed to develop nondestructive techniques that would simplify the process, be more accurate, and reduce waste production.

To meet the SFS, the MOX fuel would be irradiated in four 3484-MW(t) [1165-MW(e)] BWR-5 reactors with full MOX cores. Integral neutron absorbers (gadolinium) are added to the MOX fuel to compensate for reduced control rod worth of MOX-fueled BWRs as compared with LEU-fueled BWRs. Each reactor has four material-processing and handling sections: fresh MOX fuel storage, fuel storage pool,

Table 4.9. Nonproliferation and S&S risk assessment for the collocated PuP/MOX facility

Environment								
Facility	**Activity**	**Duration**	**Throughput**	**Waste streams**	**Maximum inventory**	**Intrasite transport**	**Number of processing steps**	**Barriers**
PuP and MOX fuel fabrication			3.2 MT/year of plutonium	Yes, <1 g/L	3.2 MT of plutonium	No	21	MAA
	Receiving, NDA, and unpacking	8 h	550–1000 kg of plutonium per batch; 4.5 kg of plutonium per batch			No, SST unload	0	
	Pit processing	8 h				No	3	Glovebox
	Mixed feed processing	8 h	0–4.5 kg of plutonium per batch			No	13	Glovebox
	MOX fuel fabrication	8 h	3.2 MT/year			No	5	Glovebox
	Fresh fuel shipping	106 d	176 assemblies, 5.31 kg of plutonium per assay			No, SST load	0	
Transport	MOX fuel fabrication to reactor		18 SSTs per batch; 5 containers with 4 assemblies each per SST					

Table 4.9. Nonproliferation and S&S risk assessment for the collocated PuP/MOX facility (cont.)

Material form										
Facility	**Activity**	**SNM input**	**SNM output**	**Quantity**	**Concentration of plutonium**	**SNM[a] category**	**Item mass/ dimensions**	**Radiation barrier**	**Chemical composition**	**Isotopics**
PuP and MOX fuel fabrication					Other fissile material present	DUU				
	Receiving, NDA, and unpacking	Metal, oxide	Metal, oxide	4.5 kg of plutonium per batch (criticality limit)	>0.90 g/g (<0.10 g/g)	IB-IID		No	Pure metal, oxides, miscellaneous	
	Pit processing	Metal	Metal			IB		No	Metal	Glovebox
	Mixed feed processing	Metal, oxide, fuels, miscella-neous	Oxide	4.5 kg (per batch)		IC		No	Oxide, miscellaneous	Glovebox
	MOX fuel fabrication	Oxide	Fuel assemblies	16.1 kg (per batch)		IC		No	Oxide, pellets, rods, assemblies	Glovebox
	Fresh fuel shipping	MOX fuel assemblies (fresh)	Fuel assemblies	176 assemblies	0.03 g of plutonium/gHM	IC	303 kg 4.55 × 0.15 m	No		
Transport	MOX fuel fabrication to reactor									

[a]See Table 2.12.

Table 4.9. Nonproliferation and S&S risk assessment for the collocated PuP/MOX facility (cont.)

S&S								
Facility	**Activity**	**Number of MBAs**	**Accounting system type**	**Nuclear measure methods**	**Classified material**	**Physically accessible**	**Access**	**Special handling equipment**
PuP and MOX fuel fabrication		5	30–50% Item	Calorimetry, gamma, segmented gamma, neutron, chemical assay			Both	No (no special handling equipment required)
	Receiving, NDA, and unpacking		Both	0.8% (Domestic) 1.5% (International)	Yes	Yes No (pits, TIDs)		
	Pit processing		Item		Yes	Yes		
	Mixed feed processing		Bulk		Yes/No	Yes		
	MOX fuel fabrication		Bulk	0.6% (Domestic) 2.5% (International)	No	Yes		No, Yes (for rods/assemblies)
	Fresh fuel shipping		Item		No	Yes		Yes (for assemblies)
Transport	MOX fuel fabrication to reactor							

reactor, and spent fuel pool. The facility also may have a dry spent fuel storage area. These processing sections are described subsequently.

The annualized throughput for each reactor is 0.8 MT of plutonium. The overall reactor site is typically ~3000 acres. The fresh MOX fuel storage vault area is ~4400 ft^2. It is sized to hold 140 shipping containers (160% of a normal reload of 176 fuel bundles) stacked in two-wide by five-high arrays with a 3-ft clearance all around for ease of inspection. The dry spent fuel storage area is ~78,000 ft^2. The fuel storage pool area is ~450 ft^2.

4.3.1.1 Facility Plot Plan

A facility layout for two existing BWR-5 reactors is shown in Fig. 4.6.

4.3.2 Existing Four-BWR Facility Modification

The BWRs under consideration for this variant are already constructed and operating. The plants may need some modification to the infrastructures of their fuel storage facilities. No other major plant modifications have been identified to support the use of MOX fuel. Two weeks of reactor physics testing on the first BWR reactor to load MOX fuel may be necessary because of the integral neutron absorbers included with the fuel.

4.3.2.1 Four-BWR Modification Schedule

After approval of intermediate line item funding, the project would begin with a year-long process to select the utility or utilities. The reactor modifications, which primarily consist of the construction of a new fuel storage facility, are estimated to take 4 years. The modification schedule is listed in Table 4.10 and in Fig. 4.7.

4.3.2.2 Four-BWR Modification Cost

The design and construction costs for the reactor facility are for the modification of four GE BWRs to burn full MOX fuel and are shown in Table 4.11. The actual modifications to the BWRs, mostly in the area of reactor physics testing, require only a small additional outage time [2 weeks for one 1165-MW(e) BWR] over normal LEU fuel operations. Therefore, $10M of replacement power needs to be purchased during the modification process (in category 8). The engineering required for the modification process (category 7) is estimated at $5M, and new buildings (new MOX fuel and spent fuel storage facilities) are estimated at $126M (in category 8). S&S modifications are estimated at $13M, and new fuel-handling equipment at $10M are also included in category 8. These costs do not include the initial MOX core, which is included in the cost of the collocated PuP/MOX facility. Contingency (AFI) has been included within each of the cost categories rather than as a separate item. Management and spares are included in modification category 8 and are not shown separately.

4.3.3 Existing Four-BWR Facility Licensing and Permitting

4.3.3.1 Four-BWR Facility Licensing and Permitting Approach

For this variant, the licensing approach is identical to that for the base case. Refer to Sect. 2.4.3.1 for the licensing approach discussion.

4.3.3.2 Four-BWR Facility Licensing and Permitting Schedule

For this analysis, a schedule for modifying an existing LWR facility license to permit the use of MOX fuel with integral neutron absorbers was followed. The process to obtain a reload permit for a new fuel fabricator is also included in the permit schedule. The license and permit schedule is shown in Table 4.12 and Fig. 4.8.

After the utility or utilities have been selected, the license amendment process is started with the preparation of the safety analysis report (SAR), the license amendment (LA) application, and the environmental report (ER). The NRC issues the safety evaluation report (SER) and the environmental assessment (EA) after completing the review of the application. The schedule includes a provision for a year-long full discovery period and an 18-month hearing and decision process by the Atomic Safety and Licensing Board (ASLB). The requirements for these processes are subject to petitions for a hearing on specific issues. After a decision is issued by the ASLB, the NRC issues the LA to the operating license (OL).

The LA process for the use of MOX fuel with integral neutron absorbers is longer than the LA process for use of MOX fuel without integral neutron absorbers, discussed in Sect. 2.4.3.2. The license and permit process includes the possibility of a full discovery

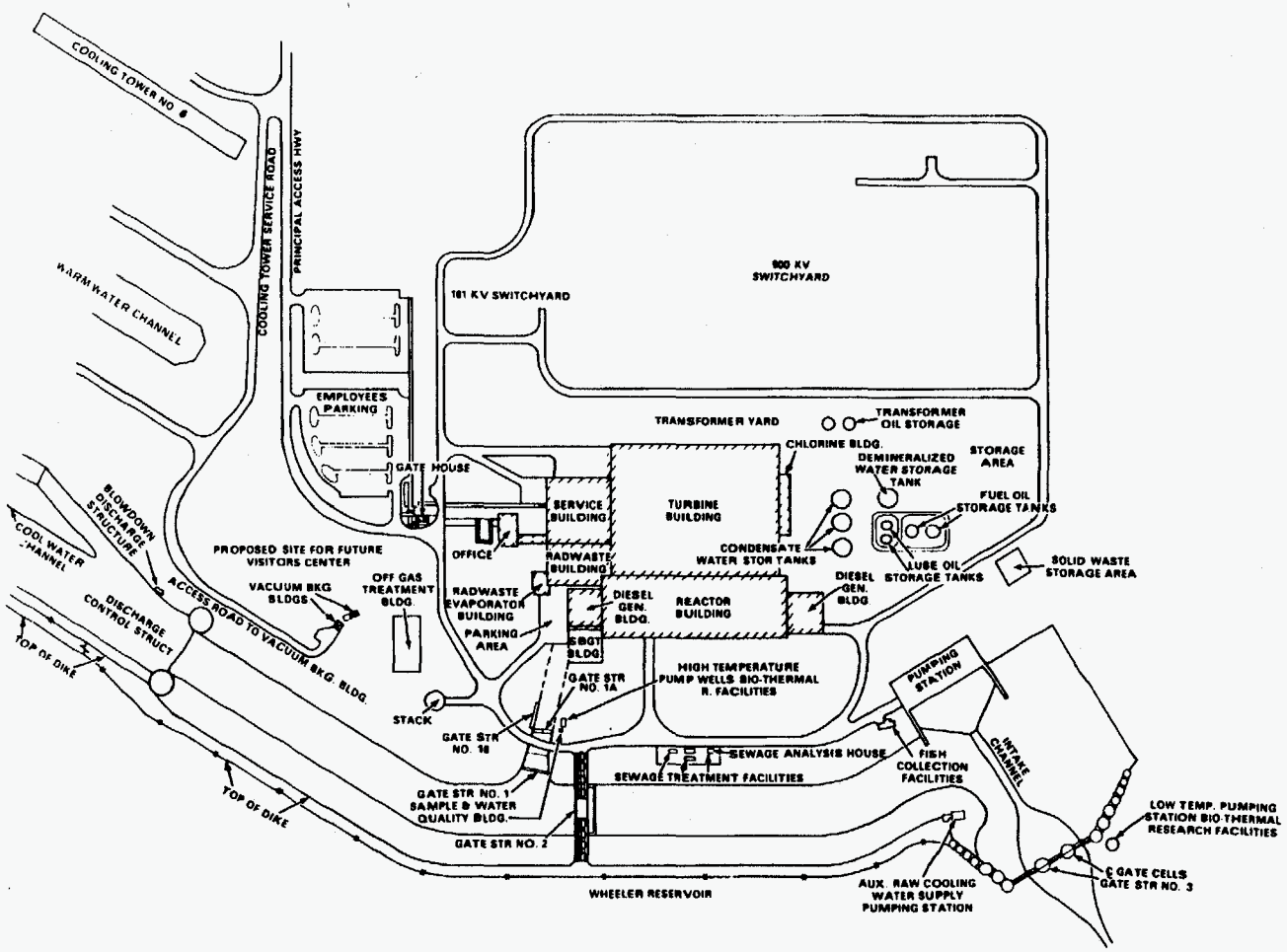


Figure 4.6. Typical two-BWR facility layout

Table 4.10. Four-BWR reactor facility modification schedule

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Intermediate Line Item Funding Approval	24	12/1996	12/1998
Utility Selection	12	12/1998	12/1999
Reactor Modifications	48	12/1999	12/2003

period and a hearing process by the ASLB as well as a longer license preparation time.

In addition, a reload permit process is followed because of the introduction of MOX fuel. A 3-year LUA license process is followed prior to inserting the LUAs into the reactor. After the LUAs have been irradiated for one cycle, 1.2 years for the BWR, a review of the LUA performance is completed. The reload permit for use of MOX fuel is granted after this review.

4.3.3.3 Four-BWR Operations-Funded Project Cost

Table 4.13 shows the assumptions and Table 4.14 shows the OPC or preoperational costs for the four-BWR variant, which total $164M; $36M of this cost is for R&D. The $103M for licensing and permitting includes NRC licensing; the site-specific EIS; licensing of the fuel transport package; and other state, federal, and local permits. The licensing cost includes reimbursement of the NRC's costs plus any licensing support work by the utility or national laboratories.

Commissioning of the four BWRs on MOX fuel is projected at $22M. No risk contingency has been added to the modification program preoperational estimates.

4.3.4 Four-BWR Facility Operations

4.3.4.1 Four-BWR Facility Shipments and Storage

Approximately 9416 LWR MOX fuel assemblies will be fabricated from the 50 MT of plutonium. The MOX fuel assemblies will be shipped from the MOX fuel fabrication facility to the four existing LWR facilities. The MOX fuel fabrication facility, in providing fuel bundles for each reactor reload, must have the capacity to store completed fuel assemblies until they are needed. In addition, each reactor provides sufficient storage capacity for a cycle reload.

Shipment Information—Table 4.15 provides estimates of the number of shipments required to transport the fresh MOX fuel from the fuel fabrication facility to the LWR facilities.

4.3.4.2 Four-BWR Process Operation Descriptions

Descriptions are provided for the material flow through the reactor facility. The data listed are per reactor.

Fresh MOX Fuel Storage Vault—The MOX fuel storage complex is planned to be a single stand-alone ex-reactor building complex at each reactor site to be used for temporary storage of both new fuel and spent fuel. In this manner, the increased security associated with fresh MOX fuel would be limited to this complex until the fuel is transferred to the reactor building just prior to refueling.

Security for the storage complex, the conceptual layout of which is shown in Fig. 4.9, would be provided by a double fence with a hardened guard post, personnel surveillance, access control, and communications. The new MOX fuel storage vault portion of this proposed facility is shown in greater detail in Fig. 4.10.

Normally, fresh reactor fuel is transported by commercial carrier using certified fresh fuel packages for LEU. Such transport is accomplished in a short period of time (within a single week) because of the high capacity and availability of commercial transport vehicles (multiple packages/truck). Transport of fresh MOX is more complicated and would require using SSTs based on the quantity of plutonium contained within each fuel assembly. For BWR assemblies, there would be ~5.3 kg of plutonium per fuel assembly. BWR assemblies, therefore, would be classified as Attractiveness Level C (high-grade material) and Category II (plutonium quantities >2 kg but <6 kg). Under DOE Order 5633.3B, all Category I (quantities >6 kg) and most Category II quantities of plutonium must be transported by SST.[1]

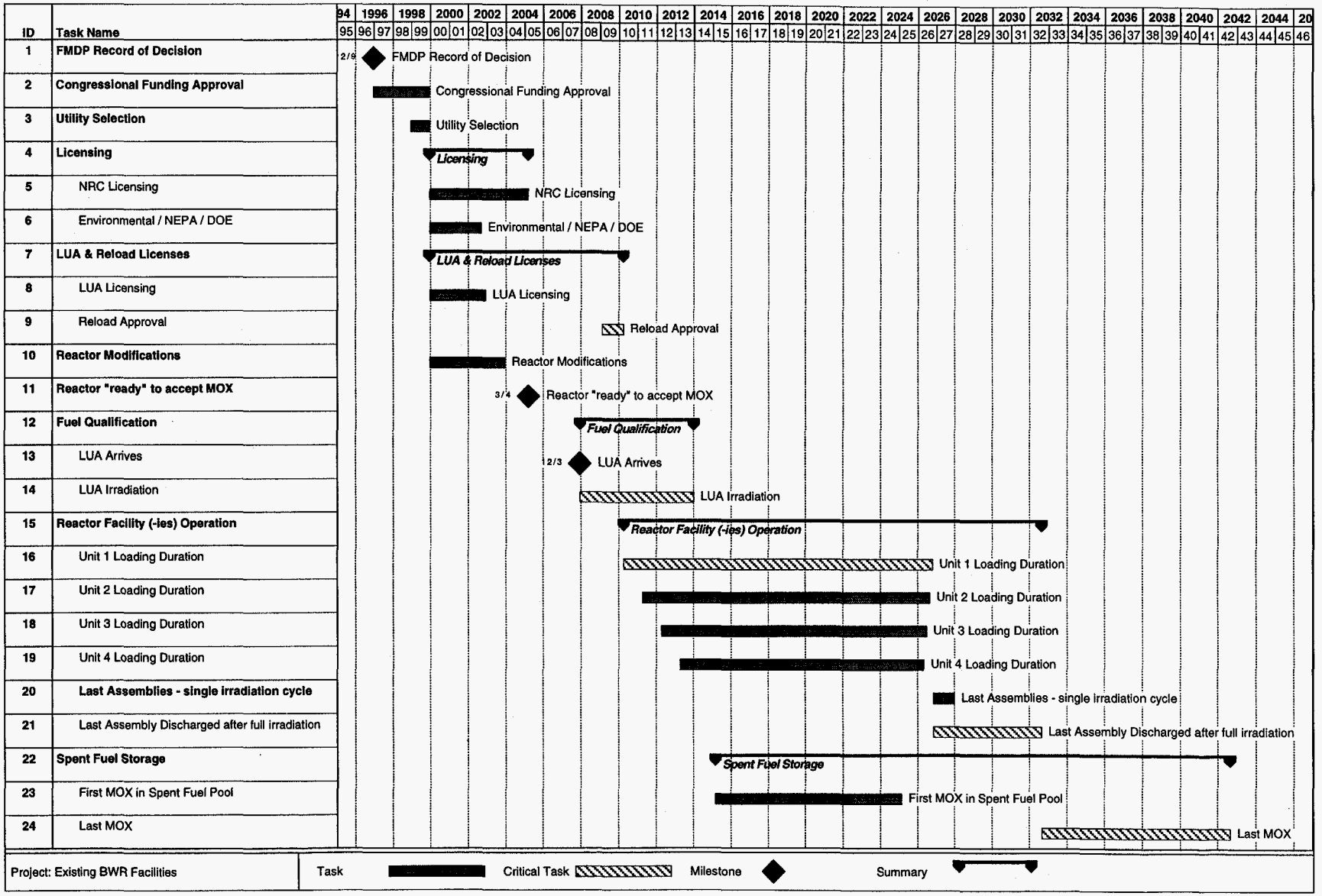


Figure 4.7. Existing LWR facility schedule summary

Table 4.11. Design and modification costs for the four-BWR reactor facility

Category	Cost category description	Cost (1996 $M)
	Capital or TEC up-front costs:	
7	Title I, II, III engineering, design, and inspection	5
8	Direct and indirect construction/modification	159
9	Construction management	0
10	Initial spares	0
11	AFI	0
12	Risk contingency	0
	TOTAL TEC	$164

Table 4.12. Existing LWR four-BWR facility license and permit schedule

Task name	Duration (months)	Start	Finish
NRC Interactions	63	12/1999	3/2005
Licensee Prepares SAR and License Amendment	18	12/1999	6/2001
Licensee Files Application			6/2001
Public Notice of Application for License Amendment	3	6/2001	9/2001
NRC Review	12	9/2001	9/2002
NRC Issues SER			9/2002
Full Discovery	12	6/2002	6/2003
Hearing by ASLB	9	6/2003	3/2004
Decision by ASLB	9	3/2004	12/2004
ASLB Issues Decision			12/2004
NRC Issues License Amendment	3	12/2004	3/2005
Notice of Amendment to Operating License			3/2005
Environmental/NEPA/NRC	33	12/1999	9/2002
Licensee Develops and Prepares ER	12	12/1999	12/2000
Licensee Files Report with NRC			6/2001
NRC Prepares and Issues Draft EA	6	6/2001	12/2001
NRC Issues Final EA	3	6/2002	9/2002
LUA and Reload Licenses	124	12/1999	4/2010
LUA Licensing	36	12/1999	12/2002
Reload Approval	14	2/2009	4/2010
Fuel Qualification—LUAs	73	12/2007	12/2013
LUA Arrives			12/2007
LUA Irradiation	73	12/2007	12/2013

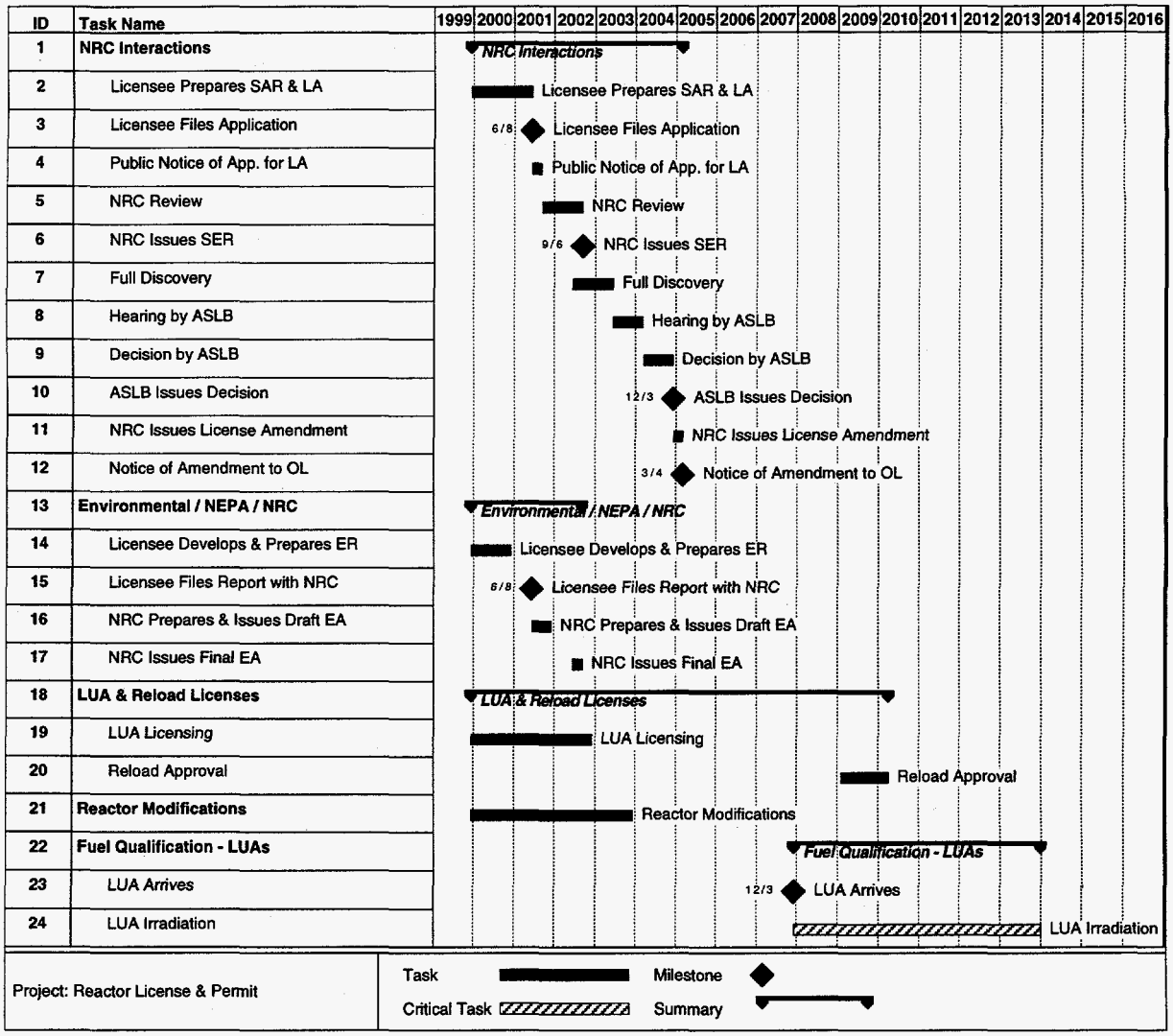


Figure 4.8. Existing LWR facility license and permit schedule

Table 4.13. BWR reactor facility costing assumptions

Average plant throughput	3.0 MT of plutonium for four units[a]
Plant location	Two two-unit BWR sites in midwestern United States
Plant owner	Private utility
Licensing	NRC
Feedstocks	Fabricated MOX from U.S. government-owned collocated PuP/MOX facility
Plant operational lifetime	Nominal 17 years to disposition 50 MT of plutonium
Time to plan campaign; license, design, and modify plants; and start up	11 years

[a]Each BWR will disposition 0.8 MT of plutonium each year when fully loaded with MOX fuel assemblies. During the transition to all MOX assemblies (at the start of the mission) and to LEU fuel (at the end of the mission), less MOX will be dispositioned per reactor each year. The overall average for the four BWRs during the entire mission (including the ramp-up and ramp-down periods) will be 3.0 MT/year.

Table 4.14 Operations-funded project costs (OPC) including licensing and other preoperational costs for four-BWR facilities

Category	Description	Cost ($M)
	Preoperational or OPC portion of investment or up-front costs:	
1	R&D	36
2	NEPA, licensing, permitting	103
3	Conceptual design	1
4	QA, site qualification, S&S plans	2
5	Postconstruction startup	22
6	Risk contingency	0
	TOTAL OPC OR PREOPERATIONAL COST	$164

Table 4.15. Parameters for fresh MOX fuel transport leg

Maximum material/package	Quantity plutonium/ campaign	Estimated packages to be shipped	Number of SST shipments/campaign
Four BWR assemblies	50 MT	2354	2354

Each SST has the capacity for a single fresh MOX fuel shipping package. Each package is a Type B radioactive material package constructed of steel that holds four BWR fuel assemblies. SSTs frequently operate in convoys of three SSTs plus associated security escorts. Each of the four BWR reactors would require 176 assemblies per reload batch. Thus, SSTs would be required to transport 44 fresh MOX fuel packages per reload, or ~15 convoys, which would occur over a period of 1 to 2 months prior to the scheduled refueling. The shipping packages would be unloaded from the SST into the steel building (anteroom), which would provide protection from the weather and screening of the SST unloading operation from unauthorized observation. Subsequently, the fuel assemblies would be removed from their packagings and be immediately moved into the vault for storage. The vault is sized to hold ~140 shipping containers (160% of a normal reload) stacked in two-wide by five-high arrays with a 3-ft clearance all around for ease of inspection. Each new batch of fuel is expected to accumulate in the new fuel storage vault over a period of 1 to 2 months.

Fuel shipping containers removed from the fuel storage vault would be lifted from the transport vehicle to the reactor building refueling floor by the reactor building crane. There the shipping container TIDs are verified and container identification recorded. The shipping containers are then set upright and opened, and the fuel bundles are transferred to the new fuel inspection stand. Figure 4.11 illustrates the flow path for fresh fuel on the refueling floor.

The new fuel inspection stand serves as a working platform for inspection and for installation of the channel (Fig. 4.11), after which the fastener assembly locks the channel and fuel bundle together as one unit. Subsequently, each assembly is transferred to one of the two fuel preparation machines attached to the spent fuel pool wall.

Fuel Storage Pool (Fresh Fuel)—The frame and movable carriage of the fuel preparation machine are located within the pool, providing a water shield. For fresh fuel, the fuel preparation machine is used only as an elevator to lower the fuel assembly into the spent fuel pool. The assembly is then transferred to a specified storage rack position in the pool for interim storage until core loading begins.

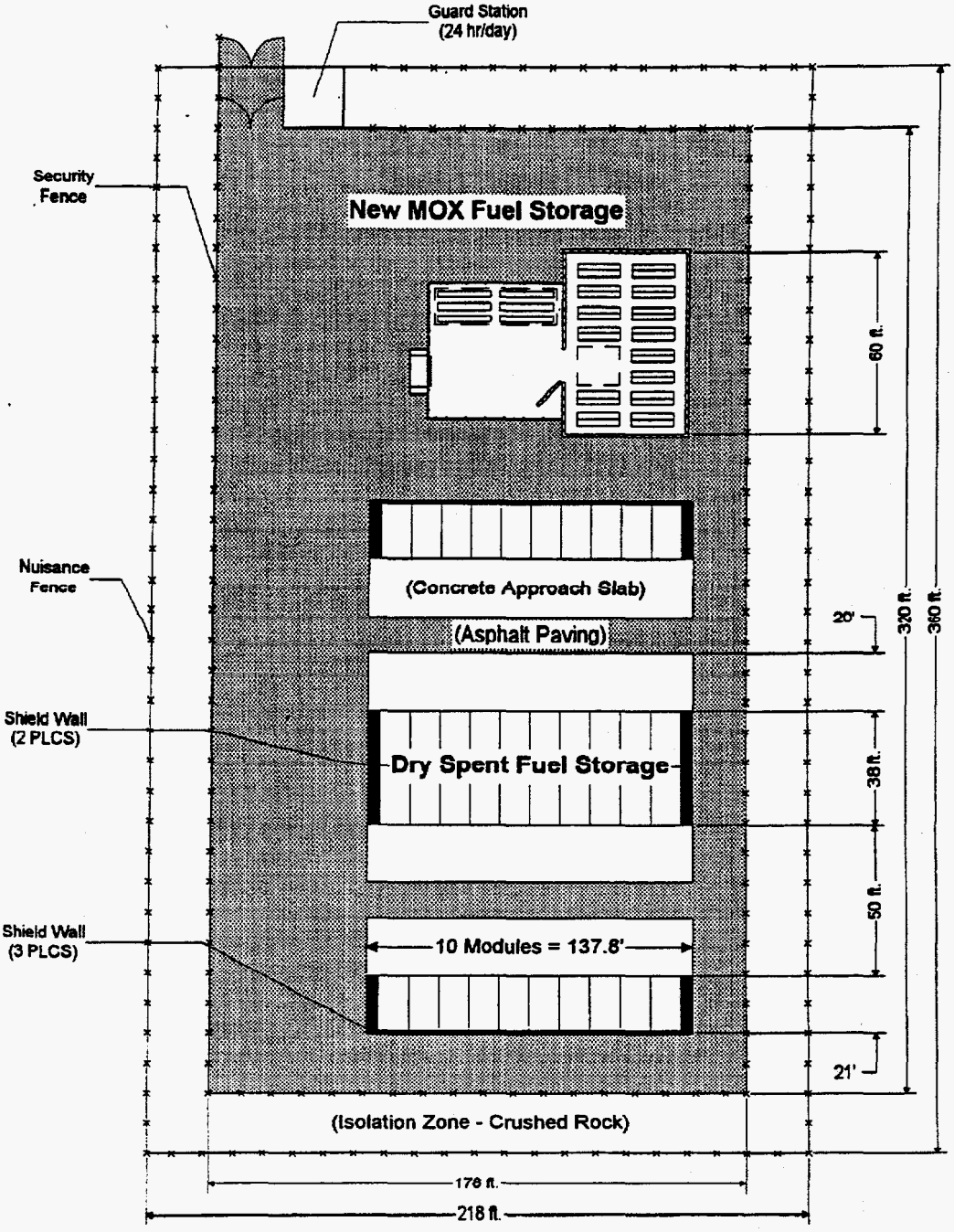


Figure 4.9. Security layout for the fresh MOX fuel storage vault

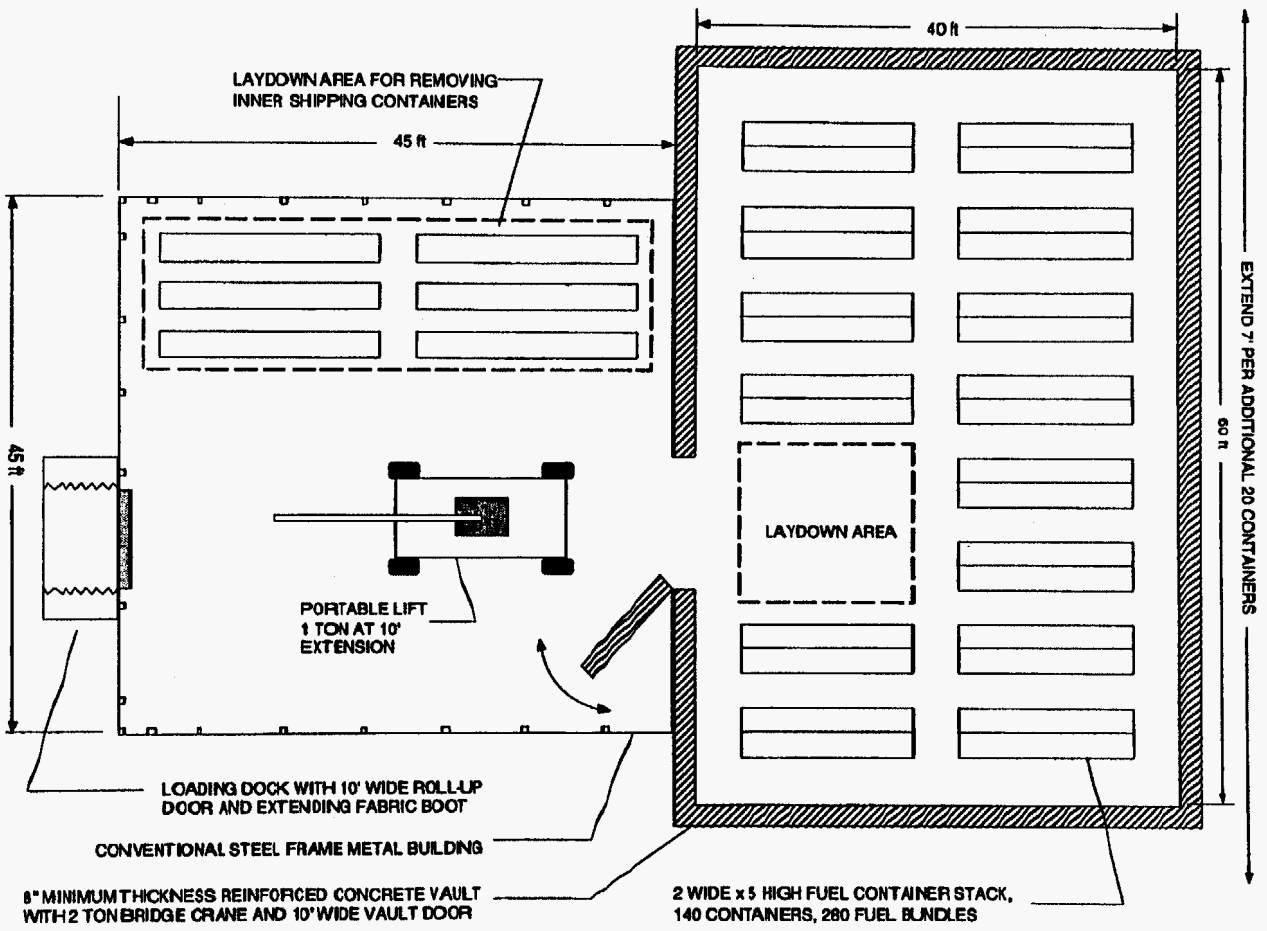


Figure 4.10. Fresh MOX fuel storage vault layout

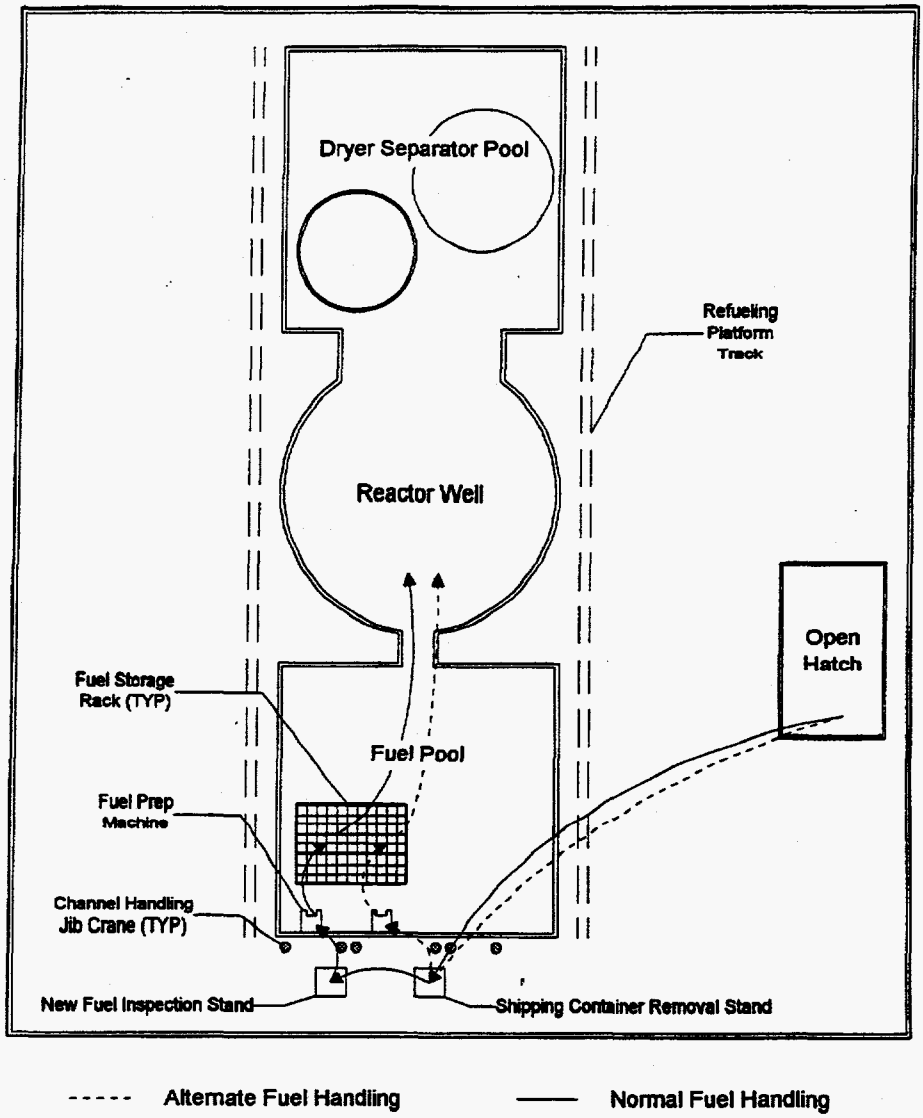


Figure 4.11. Fresh fuel flow path in reactor facility

The alternate approach illustrated in Fig. 4.11 could be used to reduce personnel exposure in light of the small increase in dose rate at the MOX bundle surface caused by the presence of americium. Here the fresh fuel would be transferred directly from the shipping container removal stand to a fuel preparation machine, which would serve as the working platform for underwater removal of the shipping spacers, inspection of the fuel, and installation of the channel.

Reactor—Transfer of fuel from the fuel storage pool to the reactor core is accomplished with the refueling platform, as indicated in Fig. 4.12. Control of the platform is from an operator station on the platform.

The planning schedule calls for each MOX batch to remain in the reactor for four cycles—a period of 4.66 years (about 56 months). Each batch undergoes irradiation for 1360 effective full-power days (EFPDs). Some fuel shifting occurs within the core at the end of each of the first three cycles. The average discharge exposure is 33,700 MWd/MT.

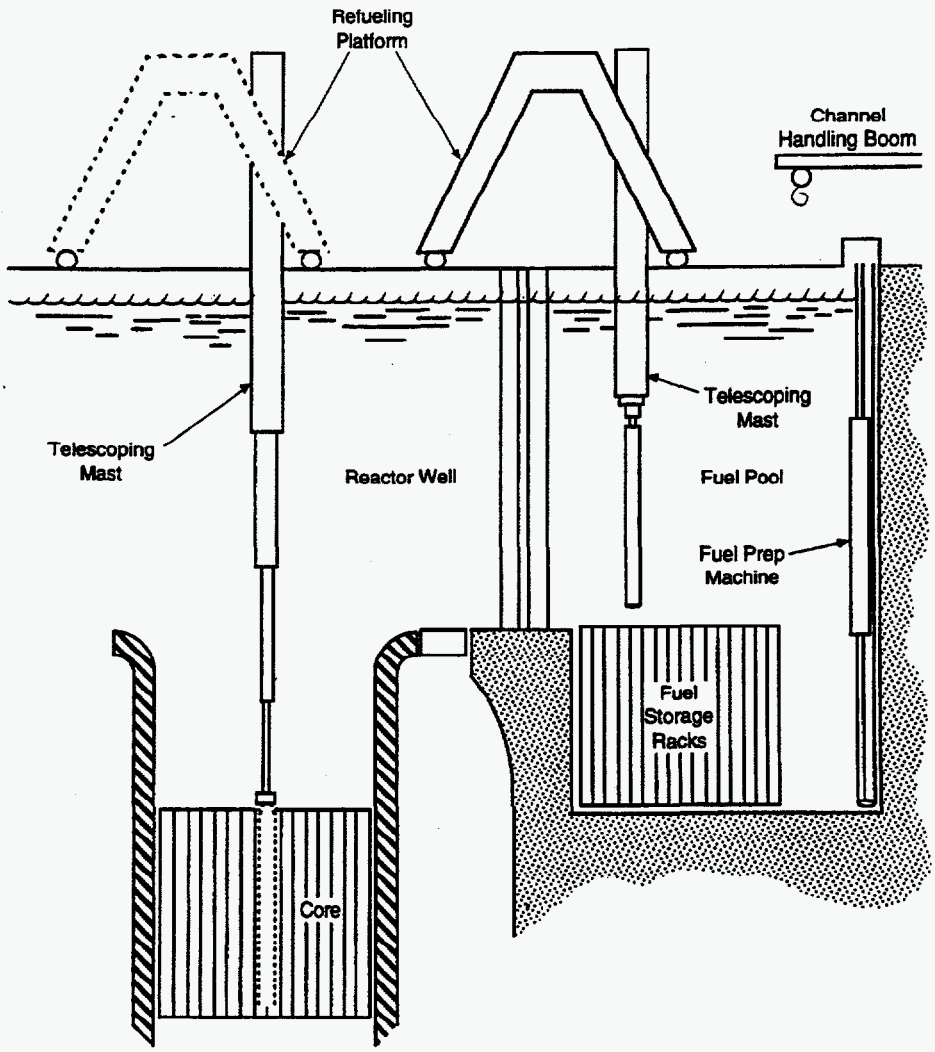


Figure 4.12. Typical BWR refueling platform

The plutonium disposition rate and pertinent fuel cycle characteristics for one GE BWR-5 reactor (BWR-4 and BWR-6 fuel cycles would be similar) are provided in Tables 4.16 and 4.17. The MOX fuel charging and discharging schedule associated with the use of four GE BWRs is shown in Table 4.18. Each reactor begins MOX operation with a partial core load of 176 MOX assemblies, which, on average, reside in the core for 4.66 years. The remaining reactors are assumed to receive their first charge of MOX assemblies at 1-year intervals. Under the assumptions employed here, the last load of 88 MOX assemblies is introduced into the first reactor 16.55 years after the initial MOX loading. (The remaining 88 assemblies in the reload are LEU fuel.)

Table 4.16. Plutonium disposition capacity and rate for an existing BWR (one reactor)

Plutonium per assembly (kg)	5.31
Plutonium dispositioned per year (MT)	0.80
Plutonium dispositioned per cycle/ reload (MT)	0.93

Table 4.17. Existing BWR representative fuel cycle characteristics

Total cycle length (days)	425
EFPD	340
Cumulative downtime per cycle	85
Reload batch size (bundles)	176
Full core size (bundles)	764
Cycle energy (GWd)	1,184
Cycle exposure (MWd/MT)	7,857
Average discharge exposure (MWd/MT)	33,700

Figures 4.2 and 4.3 depict the plutonium charged to the four reactors over the 16.55-year campaign. During this period, 9416 assemblies are loaded into the four reactors. Table 4.19 summarizes the fuel process batch characteristics of each processing step in the reactor facility.

A diagram of a typical BWR steam cycle is shown in Fig. 4.13. A diagram of the BWR reactor pressure vessel is shown in Fig. 4.14.

Spent Fuel Storage Pool (Postirradiation)—Spent fuel assemblies removed from the reactor are stored underwater in the spent fuel pool while awaiting disposition. The spent fuel storage racks are located at the bottom of the pool at a depth sufficient to provide adequate radiation shielding. The racks are designed to protect the fuel assemblies from impact damage and to withstand potential seismic loadings.

Part of the planning basis is that the irradiated MOX fuel assemblies would be allowed to cool at the reactor site for a period of 10 years. Although U.S. commercial power plants are typically designed to store at least 10 years' worth of spent fuel, the storage pools in most plants are expected to reach their capacity during the next decade, unless an HLW repository begins operation. Thus, it is probable that some storage of spent fuel external to the reactor building would be required before the spent fuel could be emplaced in an HLW repository. In this case, the final on-site transfer of MOX would be from the spent fuel pool to the dry storage area, as indicated by the final step in the process diagram.

Dry Spent Fuel Storage—Although the need for an ex-reactor spent fuel storage area is not created by the plutonium disposition mission, such an area will probably have to be used. Therefore, the planning basis for facility layout and cost estimates associated with this study includes provision for a dry spent fuel storage area.

A commercially available dry spent fuel management system is currently licensed and in service at several U.S. reactor sites. The system employs ventilated, reinforced concrete horizontal storage modules (HSMs) to store spent fuel assemblies that are sealed in stainless steel dry-shielded canisters (DSCs). Each HSM has internal flow passages to promote natural convection cooling for the enclosed DSC. The DSC serves as the containment pressure boundary and provides a leak-tight inert atmosphere for the enclosed fuel assemblies. The proposed complex consists of 40 HSMs arranged in 4 arrays of 10 modules each. Because each DSC has a capacity of 52 spent fuel assemblies, this will permit storage of more than 10 years' worth of spent fuel. This facility can be located adjacent to or inside the same guarded security area as the new fuel storage vault.

4.3.4.3 Four-BWR Operations Schedule

The LUAs are loaded into the first unit as soon as they are available and during a normal refueling period for the reactor. After completion of the LUA review during the second irradiation cycle, the first mission fuel is loaded at the next scheduled refueling period in April 2010. The MOX fuel load and discharge schedule for the four reactors is shown in Table 4.18. After the spent fuel assemblies are discharged from the reactors, they are stored in the spent fuel storage pool for 10 years before being shipped to the HLW repository facility. The existing BWR facilities operational schedule is shown in Table 4.20 and as a part of Sect. 4.3.6.

4.3.4.4 Four-BWR Operations Cost

Table 4.21 shows the costs for the additional staff and materials needed for the MOX mission above the normal staffing and materials for operation of four BWRs on LEU fuel. DOE FMDP is assumed to reimburse the BWR owner for these costs. It is assumed FMDP will continue to pay the reactor fees and incremental cost as long as MOX fuel is in a mission reactor (i.e., for 22.4 years based on the loading of the first MOX fuel load into a reactor until the last MOX bundle is removed from the reactor as shown in Table 4.18). It is estimated that 10 additional staff per reactor (half direct and half indirect FTEs assumed) will be needed in the following areas: security,

Table 4.18. MOX fuel charging/discharging schedule employing four existing GE BWRs with IFBA (integral neutron absorbers)

Time from MOX load in first reactor (years)	Assemblies loaded in reactor					Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	Cumulative			
0.00	176				176	0.935	31.2	
1.00		176			352	1.869	62.4	
1.41	176				528	2.804	93.6	
2.00			176		704	3.738	124.8	
2.41		176			880	4.673	156.0	
2.58	176				1056	5.607	187.2	
3.00				176	1232	6.542	218.4	
3.41			176		1408	7.476	249.6	
3.58		176			1584	8.411	280.8	
3.74	176				1760	9.346	312.0	
4.41				176	1936	10.280	343.2	
4.58			176		2112	11.215	374.4	
4.74		176			2288	12.149	405.6	
4.91	176				2464	13.084	436.8	116
5.58				176	2640	14.018	468.0	
5.74			176		2816	14.953	499.2	
5.91		176			2992	15.888	530.4	232
6.07	176				3168	16.822	561.6	408
6.74				176	3344	17.757	592.8	
6.91			176		3520	18.691	624.0	524
7.07		176			3696	19.626	655.2	700
7.24	176				3872	20.560	686.4	876
7.91				176	4048	21.495	717.6	992
8.07			176		4224	22.429	748.8	1168
8.24		176			4400	23.364	780.0	1344
8.40	176				4576	24.299	811.2	1520
9.07				176	4752	25.233	842.4	1696
9.24			176		4928	26.168	873.6	1872
9.40		176			5104	27.102	904.8	2048
9.57	176				5280	28.037	936.0	2224
10.24				176	5456	28.971	967.2	2400
10.40			176		5632	29.906	998.2	2576
10.57		176			5808	30.840	1029.6	2752
10.73	176				5984	31.775	1060.8	2928
11.40				176	6160	32.710	1092.0	3104
11.57			176		6336	33.644	1123.2	3280
11.73		176			6512	34.579	1154.4	3456
11.89	176				6688	35.513	1185.6	3632
12.57				176	6864	36.448	1216.8	3808
12.73			176		7040	37.382	1248.0	3984
12.89		176			7216	38.317	1279.2	4160
13.06	176				7392	39.252	1310.4	4336
13.73				176	7568	40.186	1341.6	4512

Table 4.18. MOX fuel charging/discharging schedule employing four existing GE BWRs with IFBA (cont.)

Time from MOX load in first reactor (years)	Assemblies loaded in reactor					Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	Cumulative			
13.89			176		7744	41.121	1372.8	4688
14.06		176			7920	42.055	1404.0	4864
14.22	176				8096	42.990	1435.2	5040
14.89				176	8272	43.924	1466.4	5216
15.06			176		8448	44.859	1497.6	5392
15.22		176			8624	45.793	1528.8	5568
15.39	176				8800	46.728	1560.0	5744
16.06				176	8976	47.663	1591.2	5920
16.22			176		9152	48.597	1622.4	6096
16.39		176			9328	49.532	1653.6	6272
16.55	88				9416	50.0	1669.2	6448
17.22								6624
17.39								6800
17.55								6976
17.72								7152
18.39								7328
18.55								7504
18.72								7680
18.88								7856
19.55								8032
19.72								8208
19.88								8384
20.04								8560
20.72								8736
20.88								8912
21.04								9088
21.21								9148
21.88								9208
22.04								9268
22.21								9328
22.38								9416

Notes:
1. Plutonium enrichment = 3.0%.
2. Plutonium per assembly = 5.31 kg.
3. HM per assembly = 177 kg.
4. Assemblies per core = 764.
5. Reload batch size = 176 assemblies.
6. Plutonium dispositioned per year = 3.02 MT (average).
7. HM throughput per year = 98.6 MT (average);
   HM throughput used for MOX plant sizing = 107 MT/year.
8. Cycle times including allowance for 80% capacity factor: Refueling cycle time = 425 days; for each set of 176 assemblies, the fuel in-core residence time = 4.66 years for 116 assemblies and 5.82 years for 60 assemblies.
9. Average discharge exposure = 33,700 MWd/MT.
10. Schedule includes 3-month confirmatory test with first MOX fuel batch in each reactor before full operation.
12. Initial MOX fuel loading spaced by 1 year for each reactor.
13. Each reactor begins with 176 MOX assemblies and transitions over 5 cycles to a full MOX fuel core of 764 assemblies.
14. At 16.55 years, reactors transition to LEU fuel.

Table 4.19. BWR facility batch process data

Process box number	Process cycle data	Data (average)
1. Fresh MOX fuel storage vault	Batch size (kg of plutonium) Cycle time Plutonium input form Plutonium output form	934.6 1.0 month MOX fuel MOX fuel
2. Fuel storage pool (fresh fuel)	Batch size (kg of plutonium) Cycle time Plutonium input form Plutonium output form	934.6 1.5 day MOX fuel MOX fuel
3. Reactor	Batch size (kg of plutonium) Cycle time Plutonium input form Plutonium output form	934.6 4.66 years MOX fuel MOX fuel
4. Fuel storage pool (postirradiation)	Batch size (kg of plutonium) Cycle time Plutonium input form Plutonium output form	593.5[a] 10 years Spent MOX fuel Spent MOX fuel
5. Dry spent fuel storage	Batch size (kg of plutonium) Cycle time Plutonium input form Plutonium output form	593.5[a] N/A Spent MOX fuel Spent MOX fuel

[a]The postirradiation batch size is based on the ratio between the plutonium mass in spent fuel and plutonium mass in new fuel found in GE report *Study of Plutonium Disposition Using Existing GE Boiling-Water Reactors.*

accountability, in-reactor staff, and common services and training. The cost of the additional staff and their support materials, equipment, and overhead is calculated in category 13 at $3.0M/year for four reactors.

No incremental consumables or utilities were identified. Capital replacements over the 22.4-year plutonium disposition mission are estimated at $1.5M/year. No incremental waste handling costs were identified when using MOX fuel instead of LEU fuel. All additional oversight costs are included under personnel costs. (category 13). D&D of the reactors (category 20) is the responsibility of the U.S. BWR owner at the end of the reactors' lives and involves no government funds. (It is assumed that the use of MOX fuel introduces no issues that will affect the D&D costs for the four reactors. Also, because the reactors are not owned by the U.S. government, no revenues accrue; hence, zero revenue is shown in category 21.)

The incentive fee to the BWR owner (category 22) is calculated on the formula used for the other reactor alternatives, that is, $25M/year/reactor pair for the first 5 years followed by $10M/year for the remaining years (11.6 years in this case). This cost estimate for incentive fee is arbitrary and does not reflect any decision on actual fees to be negotiated. Because business negotiable items are not included in the August 1996 TSR, the fee does not appear in Table 4.1 of the TSR.

Approximately $2.9M/year in transportation costs has been calculated for transportation of MOX bundles from the MOX fuel fabrication facility to the two 2-unit BWR sites, which are assumed to be located in the midwestern United States. If the fee and transportation are included, the reactor part of the four-BWR variant will cost an average of ~$36M/year for the first 16.6 years.

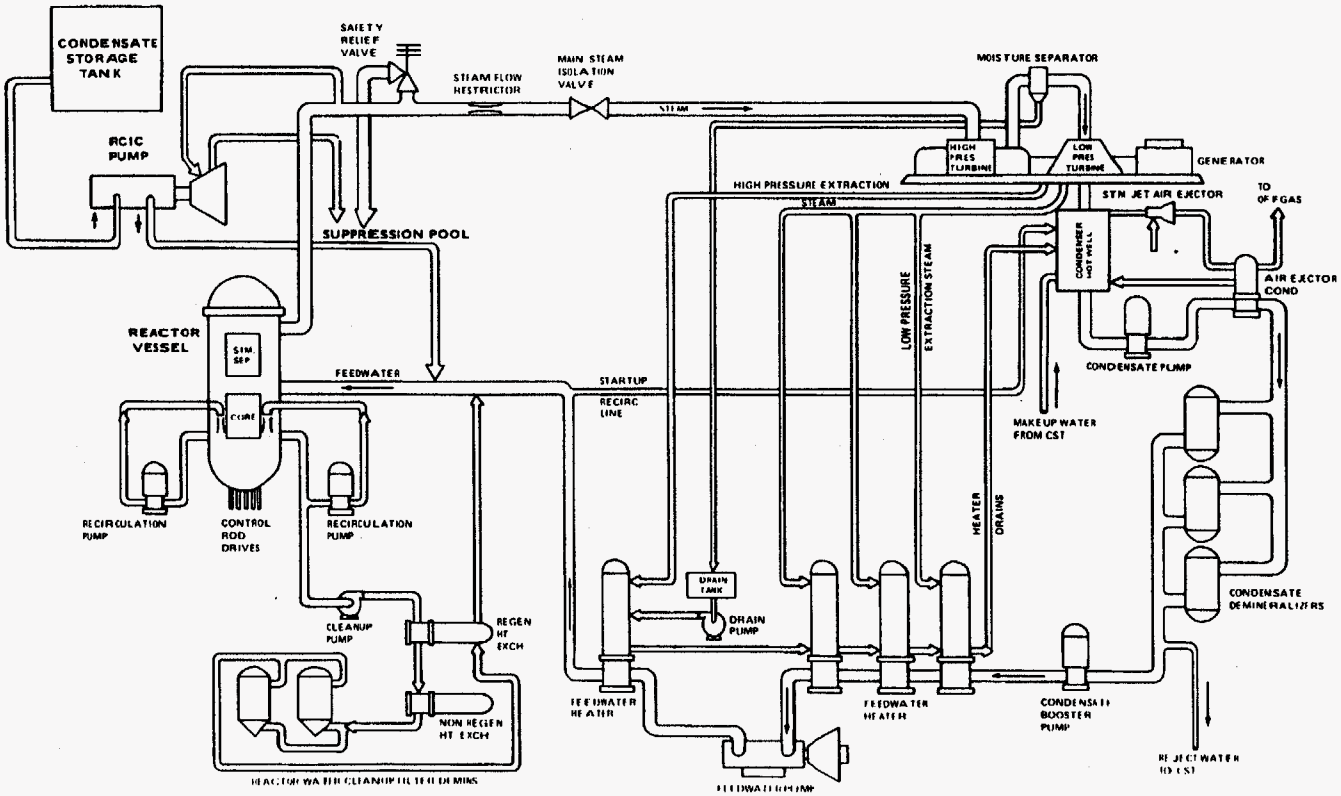


Figure 4.13. Typical BWR steam cycle diagram

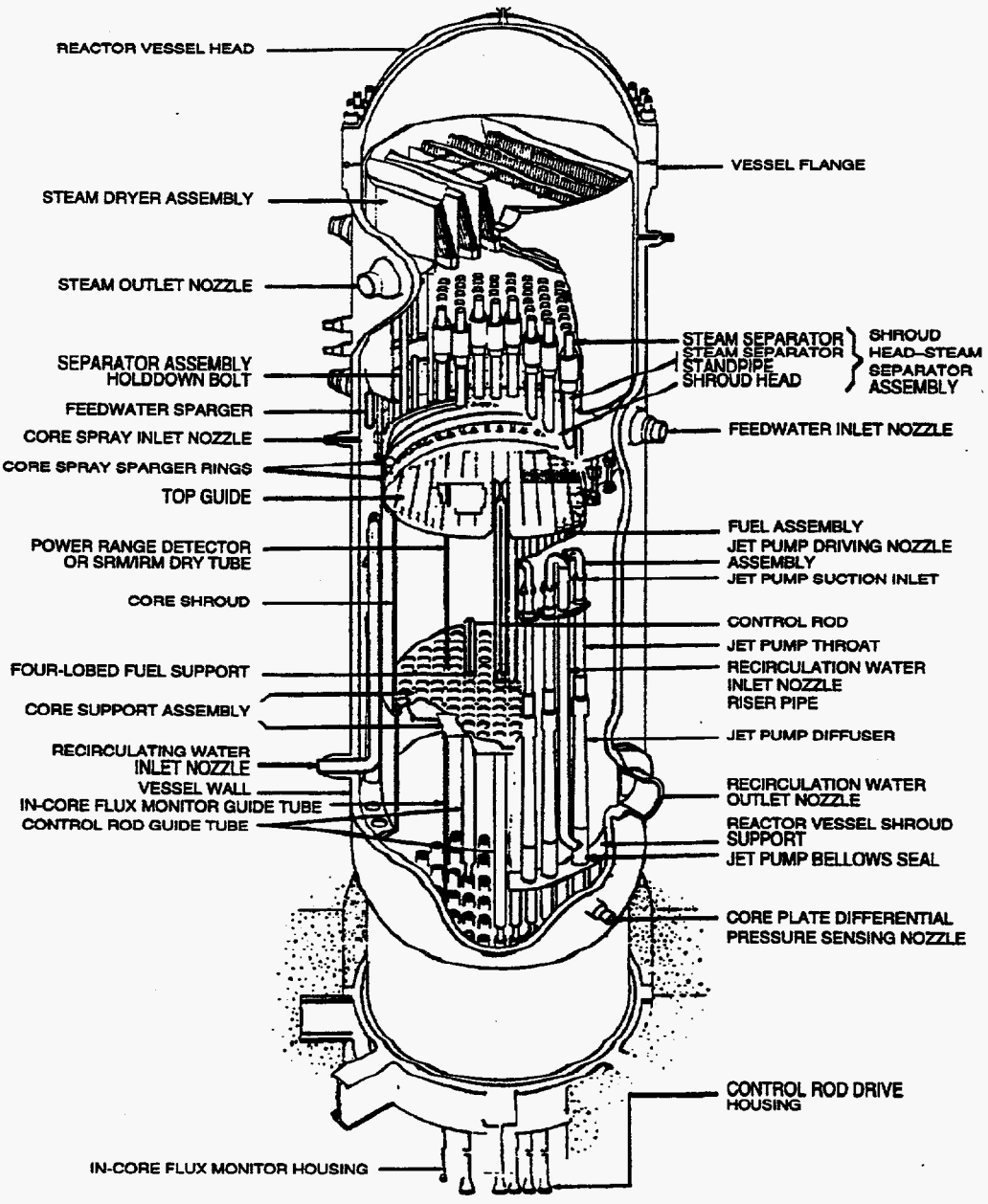


Figure 4.14. BWR reactor pressure vessel

Table 4.20. Existing four-BWR facility operations schedule

Task name	Duration (months)	Start	Finish
Reactor "Ready" to Accept MOX			3/2005
Fuel Qualification	73	12/2007	12/2013
LUA Arrives			12/2007
LUA Irradiation	73	12/2007	12/2013
Reactor Facility (-ies) Operation	268	4/2010	8/2032
Unit 1 Loading Duration	199	4/2010	10/2026
Unit 2 Loading Duration	185	4/2011	8/2026
Unit 3 Loading Duration	171	4/2012	6/2026
Unit 4 Loading Duration	157	4/2013	5/2026
Last Assemblies—Single Cycle	14	10/2026	12/2027
Last Assembly Discharged	70	10/2026	8/2032
Spent Fuel Storage	330	3/2015	8/2042
First MOX in Spent Fuel Pool	120	3/2015	2/2025
Last MOX in Spent Fuel Pool	120	8/2032	8/2042

Table 4.21. Recurring and other LCCs for a four-BWR reactor facility

Category	Cost category description	Cost	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Other LCCs for four-BWR units: campaign length = 16.6 years for fee and transportation; 22.4 years for staff size and capital upgrades[a]		
13	Operations and maintenance staffing		
	Incremental staff size (headcount), 10 persons per reactor		
	Staffing cost (22.4 years)	67	3.0
14	Consumables (including utilities)	0	0
15	Major capital replacements or upgrades (22.4 years)	34	1.5
16	Waste handling and disposal	0	0
17	Oversight	0	0
18	M&O contractor fees		
19	PILT to local communities		
	TOTAL REACTOR RECURRING COSTS	$101	$4.5
20	D&D	0	
21	Revenues	0	0
22	Incentive fee to utility (16.6 years)	482	29.0
23	Transportation of plutonium forms to facility (16.6 years)	49	2.9
24	Storage of plutonium at existing 94-1 site facility		
	TOTAL OTHER LCC	$632	$36.4[b]

[a] The time from the date the first MOX fuel goes into a reactor to the date the last MOX fuel is introduced is 16.6 years. The time from the date the first MOX fuel goes into a reactor until the last of the MOX fuel is taken out of the reactor is 22.4 years.

[b] Applies only to first 16.6 years in this analysis.

4.3.5 Four-BWR Facility Conversion to LEU

At the end of the plutonium disposition mission, the four BWRs may have some useful economic life remaining. If so, the utility owners would change fuel supplies from MOX fuel back to LEU fuel for the remainder of the BWR lifetime.

4.3.5.1 Conversion to LEU Fuel Schedule

The last MOX core load contains 88 MOX fuel assemblies; the other 88 fuel assemblies are LEU fuel. Subsequent core loads are all LEU fuel.

4.3.5.2 Conversion to LEU Costs

No special LCC category was created for this purpose. All costs for conversion back to LEU are included in the fee and in the recurring costs.

4.3.6 Four-BWR Facility Schedule Summary

The overall existing BWR facility implementation schedule is summarized in Table 4.22 and shown in Fig. 4.7. This facility schedule is also discussed as part of the overall alternative schedule in Sect. 4.5.1. The critical path for this facility is the availability of the LUAs and is shown in Fig. 4.7. The reactors will be ready to accept MOX LUAs almost 3 years before they are available.

4.3.7 Four-BWR Facility Cost Summary

Table 4.23 shows all of the LCCs for the four-reactor facility in the 24-category format. Up-front (investment) cost to the government totals $328M for all four BWRs. Costs for the entire reactor part of the mission total less than $1B, including the incentive fee.

Table 4.22. Existing LWR facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Utility Selection	12	12/1998	12/1999
Licensing and Permitting	63	12/1999	3/2005
LUA and Reload Licenses	124	12/1999	4/2010
Reactor Modifications	48	12/1999	12/2003
Reactor "Ready" to Accept MOX			3/2005
Fuel Qualification	73	12/2007	12/2013
Unit 1 Loading Duration	199	4/2010	10/2026
Unit 2 Loading Duration	185	4/2011	8/2026
Unit 3 Loading Duration	171	4/2012	6/2026
Unit 4 Loading Duration	157	4/2013	5/2026
Last Assemblies—Single Irradiation Cycle	14	10/2026	12/2027
Last Assembly Discharged After Full Irradiation	70	10/2026	8/2032
Spent Fuel Storage	330	3/2015	8/2042

Table 4.23 Summary of LCCs for two 2-unit BWR facilities

Category	Cost category descriptions	Lump sum (1996 $M)	Annual (1996 $M/year)
	Preoperational or OPC up-front costs:		
1	R&D	36	
2	NEPA, licensing, permitting	103	
3	Conceptual design	1	
4	QA, site qualification, S&S plans	2	
5	Postconstruction startup	22	
6	Risk contingency	0	
	TOTAL OPC	$164	
	Capital or TEC up-front costs:		
7	Title I, II, III engineering, design, and inspection	5	
8	Direct and indirect construction/modification	159	
9	Construction management	0	
10	Initial spares	0	
11	AFI	0	
12	Risk contingency	0	
	TOTAL TEC	$164	
	TOTAL UP-FRONT COST (TPC)	$328	
	Other LCCs:		
13	O&M staffing[a] incremental staff size, 10 persons per reactor	67	3.0
14	Consumables including utilities	0	
15	Major capital replacements or upgrades	34	1.5
16	Waste handling and disposal	0	
17	Oversight	0	
18	M&O contractor fees		
19	PILT to local communities		
20	D&D	0	
21	Revenues (if applicable)	0	
22	Fees to privately owned facilities (incentive fee)[b]	482	29.0
23	Transportation of plutonium forms to facility[b]	49	2.9
24	Storage of plutonium at existing 94-1 site facility	N/A	
	TOTAL OTHER LCC	$632	$36.4[c]
	GRAND TOTAL ALL LCC	$960	

[a]Reactor incremental staffing and capital replacements or upgrades are based on a 22.4-year duration.
[b]Transportation and fee are based on a 16.6-year duration.
[c]Applies only to first 16.6 years.

4.3.8 Four-BWR Facility S&S Summary

The use of four privately owned BWRs and full MOX plutonium cores should not significantly affect the threat and/or risk for the reactor facilities. There will be differences in the size, mass, and characteristics of the fuel assemblies (both fresh and irradiated) as well as the reactor operations cycle, which would slightly affect the S&S issues and concerns but should not significantly affect the risk to the facility. Table 4.24 provides information about the material flow of plutonium through this facility and a description of the material and its attractiveness level.

Table 4.24. Nonproliferation and S&S risk assessment for the collocated existing BWR facility

Environment								
Facility	**Activity**	**Duration**	**Throughput**	**Waste streams**	**Maximum inventory**	**Intrasite transport**	**Number of processing steps**	**Barriers**
Reactor (data for one reactor, four reactors used in alternative)		~180 months	0.8 MT of plutonium		935 kg of plutonium (fresh fuel), 4.6 MT irradiated fuel		1	PA VA/MAAs
	Fresh MOX fuel storage vault	1–2 months	935 kg of plutonium, batch 18 SSTs per reload batch, 5.31 kg plutonium/assembly	No	140 containers	Yes—transport to reactor building, SST unload		Separate stand alone building, TIDs
	Fuel storage pool	0.05–0.1 month	935 kg per batch	No		No		TIDs
	Reactor (0.63 kg plutonium burnup)	55.9–60 months (four cycles)	935 kg per batch (fresh), 176 assemblies per reload (60 stay for a fifth cycle)	No	764 assemblies (full core), 2556 kg of plutonium	No	1	Containment building
	Fuel storage pool (postirradiated)	120 months	589 kg of plutonium (irradiated)	No	2007 kg of plutonium	No	0	In fuel storage basin
	Dry spent fuel storage	Not applicable		No	52 assemblies per DSC	Yes (to dry storage)		LA 40 HSMs
Transport	MOX fuel fabrication to reactor							

Table 4.24. Nonproliferation and S&S risk assessment for the collocated existing BWR facility (cont.)

Material form										
Facility	**Activity**	**SNM input**	**SNM output**	**Quantity**	**Concentration of plutonium**	**SNM[a] category**	**Item mass/ dimensions**	**Radiation barrier**	**Chemical composition**	**Isotopics**
Reactor					No other FM	DUU DUI				
	Fresh MOX fuel storage vault	MOX fuel assemblies (fresh)	MOX fuel assemblies (fresh)	934.6 kg	5.334 kg of plutonium/178 kg of HM	IC	303 kg 4.5 × 0.15 m	No	MOX	0.94 ^{239}Pu 0.057 ^{240}Pu 0.003 ^{241}Pu per assembly
	Fuel storage pool	MOX fuel assemblies (fresh)	MOX fuel assemblies (fresh)	934.6 kg		IC		No	MOX	
	Reactor	MOX fuel assemblies (fresh)	MOX fuel assemblies (irradiated)	589 kg of plutonium (irradiated)		IC (in) IVE (out)		No (in) Yes (out) 1.89E7	MOX	At discharge 0.421 ^{239}Pu 0.353 ^{240}Pu 0.151 ^{241}Pu 0.66 ^{242}Pu
	Fuel storage pool (irradiated)	MOX fuel assemblies (irradiated)	MOX fuel assemblies (irradiated)	589 kg of plutonium	3.34 kg of plutonium/172 kg of HM	IVE or IID if mod irradiated		Yes 1.78E4		At 10 years 0.447 ^{239}Pu 0.373 ^{240}Pu 0.098 ^{241}Pu 0.069 ^{242}Pu
	Dry spent fuel storage	MOX fuel assemblies (irradiated)	MOX fuel assemblies (irradiated)			IVE or IID if mod irradiated		Yes		
Transport	Reactor to repository									

4.3.9 Four-BWR Facility Technical Viability Summary

Technical viability issues for the four-BWR facility are identical to those of the existing LWR base-case reactors (Chap. 2), except for the issues related to integral burnable neutron absorbers.

Technical Risks—Reactor operation to consume plutonium—MOX fuel has been irradiated both domestically and internationally. However, the irradiation experience base does not cover all of the issues associated with MOX burning as part of this plutonium disposition mission. For this reason, the technology has been judged to be at the prototypic stage of development. The outstanding issues are inclusion of burnable neutron absorbers into the MOX fuel, presence of americium in the MOX fuel, use of weapons-grade rather than reactor-grade plutonium, severe accident performance of the fuel, and use of a full-MOX core rather than approximately one-third core. None of these issues are judged to be impossible to overcome. The best evidence available suggests that the MOX performance should equal or exceed the performance of similar LEU fuel.

Burnable neutron absorbers have never been incorporated into MOX fuel. However, modern MOX fuels are very homogeneous such that the plutonium exists in very small particles surrounded by an LEU matrix. If burnable neutron absorbers are added during the micronization, they should likewise become homogeneously distributed throughout the fuel matrix. On average, the burnable neutron absorber particles will "see" a surrounding uranium matrix, a chemical condition similar to that currently existing in certain LWR-LEU fuels. This behavior is expected to be verified as part of the fuel development and demonstration program.

Thus, while issues associated with reactor operation do exist, none of the issues presented are judged to add significant risk to the overall mission success. Even if the performance is not as expected, engineering solutions can be found for the difficulties. The overall risk associated with reactor operation to irradiate plutonium is judged to be low.

R&D Needs—As stated before, burnable neutron absorbers have never been incorporated into MOX fuel. Test programs have been discussed previously. Also, the severe accident performance of MOX fuel needs to be verified. Both of these needs can be fulfilled through a fuel development and demonstration program.

A number of engineering development and R&D tasks have been identified to deal with reactor operation on MOX, with the majority focusing on fuel development activities. These include the following:

- validation of neutronics computer codes and NRC confirmatory review;
- validation of neutronics codes incorporating models for burnable neutron absorbers;
- experimentation to support analysis in the first two items;
- LTA for BWRs;
- development/update of fuel mechanical performance computer programs and development of independent code for NRC;
- preparation of a severe accident database for NRC;
- update of the Safety Analysis Report;
- performance of fuel management calculations for full MOX core for submission to NRC;
- analyses for fresh fuel staging, storage, security, and shielding considerations; and
- fuel thermal analysis.

Because spent MOX fuel is very similar to spent LEU fuel, the technologies associated with spent fuel operations are judged to be at the commercial stage of development. All of these spent fuel technologies have been demonstrated domestically for LEU fuel and internationally for both LEU and MOX fuels. Some limited analysis may be required to quantify the differences between the fuels. However, it is unlikely that any appreciable development will be required to accommodate the MOX fuel.

4.4 HLW Repository

4.4.1 HLW Repository Description

For this variant, the repository is identical to the base case. Refer to Sect. 2.5.1 for the HLW repository description.

4.4.2 HLW Repository Design and Construction

For this variant, the repository design and construction is identical to the base case. Refer to Sect. 2.5.2 for the HLW repository description design and construction discussion.

4.4.3 HLW Repository Licensing

For this variant, the repository licensing is identical to the base case. Refer to Sect. 2.5.3 for the HLW repository description licensing discussion.

4.4.4 HLW Repository Operations

4.4.4.1 HLW Repository Shipments and Storage

It is assumed that the Civilian Radioactive Waste Management System (CRWMS) transportation system will be used to transport the spent fuel from the reactors to the repository. The CRWMS transportation system includes truck- and rail-based spent fuel cask systems. Some U.S. reactors that cannot accommodate large rail casks will need to use smaller spent fuel casks transported by truck.

Shipment Information—Although beyond the scope of the FMDP mission, the spent fuel will eventually be transported to the geologic repository for emplacement. Table 4.25 provides estimates of the number of shipments required.

4.4.5 HLW Repository Schedule Summary

The spent MOX fuel is scheduled to be delivered to the repository facility from March 2025 to September 2042. The HLW repository facility schedule summary is shown in Table 4.26 and as a part of Sect. 4.5.1.

4.4.6 HLW Repository Cost Summary

For this variant, the repository cost summary is identical to the base case. Refer to Sect. 2.5.6 for the cost summary.

4.5 Four-BWR Variant Summary

4.5.1 Four-BWR Variant Schedule Summary

The four-BWR alternative (with collocated PuP/MOX facility) schedule is a combination of the individual facility schedules discussed previously. This overall schedule is summarized in Table 4.27 and shown in Fig. 4.15. The plutonium disposition mission begins when the first mission fuel is loaded into a reactor in April 2010 and is complete after the last core load, which contains MOX fuel assemblies, has been irradiated for a single cycle in December 2027. The overall mission time is 17.7 years and starts 13.3 years after ROD.

The critical path for this alternative is the licensing, design, and construction of the new facility for the collocated PuP and MOX fuel fabrication facility.

Table 4.25. Parameters for spent MOX fuel transport leg

Maximum material/package	Quantity of plutonium/campaign	Estimated number of packages to be shipped	Number of cask shipments/campaign
40 BWR assemblies	~50 MT	236	236

Table 4.26. HLW repository facility schedule summary

Task name	Duration (months)	Start	Finish
Licensing	102	3/2002	8/2010
Construction	66	3/2005	8/2010
Repository Opening Date			8/2010
MOX Delivery	210	3/2025	9/2042
Transportation of First MOX to Repository	1	3/2025	3/2025
Transportation of Last MOX	1	8/2042	9/2042

Table 4.27. Four-BWR alternative with collocated PuP/MOX fuel fabrication facility schedule summary

Task name	Duration (years)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval Process	3	12/1996	12/1999
Collocated PuP & MOX Fuel Fabrication Facility	29.8	10/1995	7/2025
Fuel Qualification Process	5	4/1996	4/2001
R&D	3	10/1995	9/1998
Licensing, Permitting, and Siting	5	1/1998	1/2003
Design	5.0	12/1996	11/2001
Facility Modification	4.4	1/2002	6/2006
Preoperation	2	6/2005	6/2007
Fabrication of LUAs	0.5	6/2007	12/2007
MOX Fabrication Operation	15.6	12/2007	7/2023
D&D	2	7/2023	7/2025
Reactors	43.7	12/1998	8/2042
Utility Selection	1	12/1998	12/1999
Licensing	5.2	12/1999	3/2005
Reactor Modifications	4	12/1999	12/2003
Reactor "Ready" to Accept MOX			3/2005
Irradiation of Lead Use Assemblies	6.1	12/2007	12/2013
MOX Loading Duration	16.6	4/2010	10/2026
Single Irradiation Cycle of Last MOX	1.2	10/2026	12/2027
Spent Fuel Pool	27.5	3/2015	8/2042
Repository			
Licensing	8.5	3/2002	8/2010
Construction	5.5	3/2005	8/2010
MOX Delivery Duration	17.5	3/2025	9/2042

The schedule risk for the collocated PuP and MOX fuel fabrication facility is the same as for the stand-alone PuP facility and MOX fuel fabrication facility in the other reactor-based alternatives. The additional schedule risk for obtaining a license modification for using MOX fuel with integral neutron absorbers has been included in the license and permitting schedule for the LWR reactor facility in this alternative.

4.5.2 Four-BWR Variant Cost Summary

For this case it was decided to use a new collocated PuP and MOX fuel fabrication plant as part of the four-BWR existing reactor variant.

Of the $1.38B in investment (TPC) costs for all facilities, the collocated PuP/MOX fabrication facility cost is the largest cost at $1.05B. The PuP portion of this facility processes 5 MT of plutonium/year for 10 years, and the MOX fuel fabrication portion of the facility processes 98.8 MTHM/year for 15.6 years. The combined TPC capital cost would be several $100M lower than separately constructed and separately sited PuP and MOX fuel fabrication facilities.

The design and modification cost (TEC) for the four BWRs is $164M. This cost includes the cost of 2 weeks of replacement power during the modification, testing, and MOX fuel retrofit outage. The investment

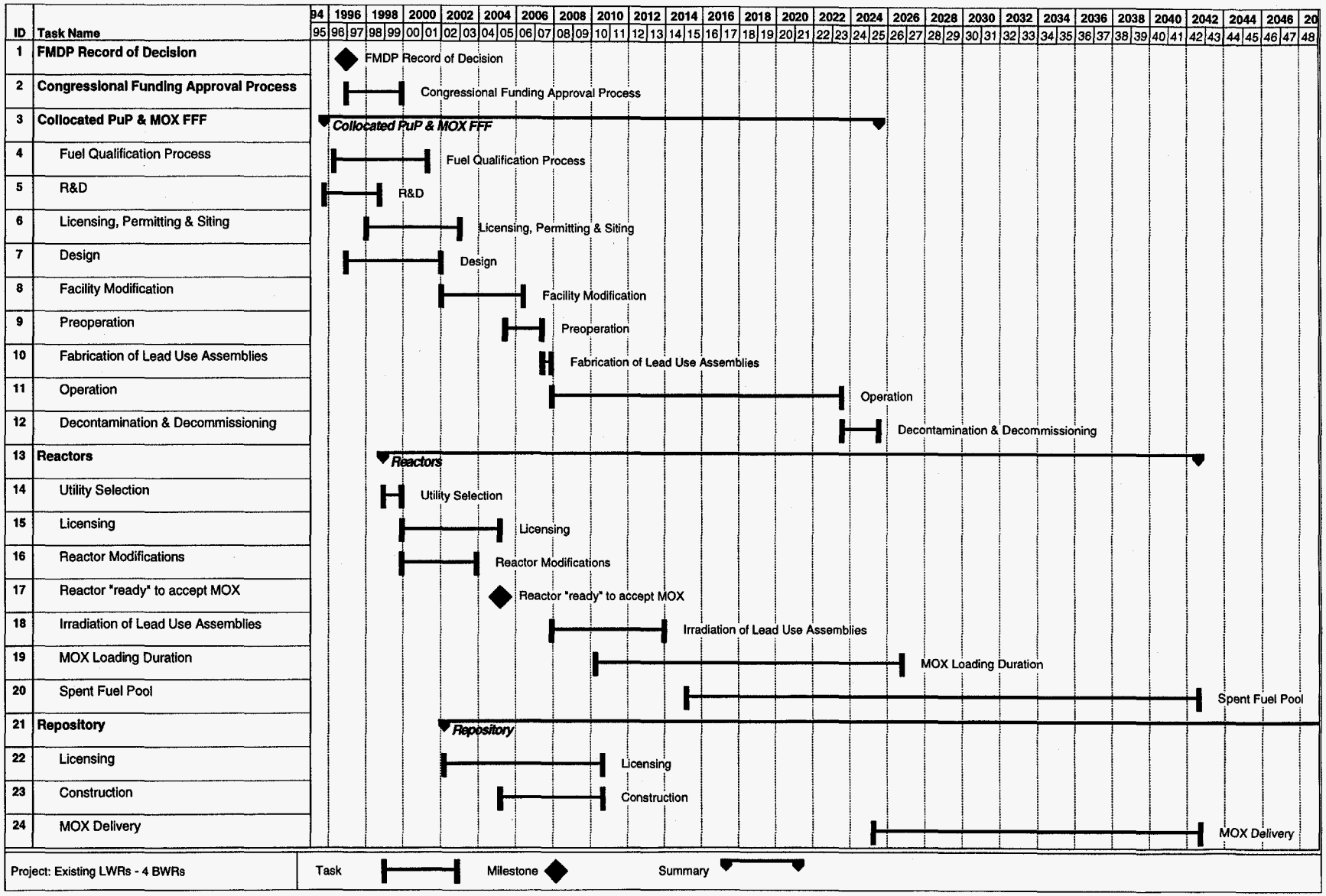


Figure 4.15. Existing LWR alternative collocated PuP/MOX fuel fabrication facility case schedule summary

cost (TPC) for the BWR reactors of $328M also includes modification, R&D, and licensing.

Figure 4.16 shows the facility investment costs graphically and also breaks down the other LCCs. Table 4.28 shows the LCCs for all facilities in the 24-category format. It should be noted that the $482M incentive fee paid to the utility has been broken out separately from its higher level category—O&M and other LCCs. This has been done to allow comparison with other reactor options. The bottom of Table 4.28 shows the total LCC without the incentive fee. The fee was not considered in the TSR. The recurring cost or O&M plus other LCCs category is also largest for the combined PuP/MOX fuel fabrication facility compared to the incremental reactor annual costs. It averages almost $149M/year for the 10 years when both parts of the combined facility operate simultaneously.

The staffing for both facilities is summarized in Table 4.29. The incremental operating cost (without incentive fee) for the reactor portion of the four-BWR MOX mission is slightly over $7M/year including transportation of MOX to the reactor site.

The LCCs for all facilities combined are shown in Fig. 4.17. The total D&D cost of $456M for the PuP and MOX facilities is shown on this chart. The U.S. government is not responsible for any D&D of the private PWR reactors. No repository cost is shown. The utility is already paying the 1-mill/kWh waste fee. The analysis assumes that this fee will cover the cost of spent MOX fuel disposal in the same manner it covers spent LEU fuel.

The analysis assumes that the government will sell MOX fuel to the private utility at the mass-equivalent price of BWR LEU fuel or $1214/kg HM. This accounts for the $2.0B fuel credit (revenue) to the U.S. government. Because of the lower plutonium and ^{235}U loadings of BWR fuel as compared to PWR fuel, the total amount of LEU fuel displaced per reactor is larger than for PWRs.

Figure 4.18 shows the annual constant dollar cash flow to the U.S. government for this alternative. The cash flows are front-end loaded because of the need to complete modification of the four BWRs and construct the entirely new combined facility for PuP and MOX fuel production. The effect of the offsetting fuel displacement credit (MOX sales revenue) is also shown. When the net cash flows are discounted at a 5% real discount rate, a TDLCC of $1.35B results.

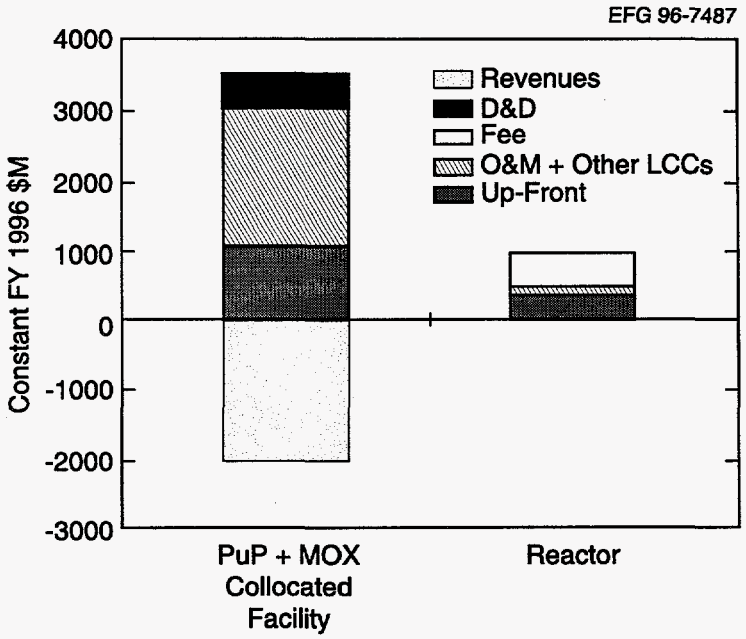


Figure 4.16. LCCs and revenues by facility

Table 4.28. LCC summary for all facilities in 24-category format for the four-BWR variant

Category	Cost category description	PuP collocated plant		MOX fuel fabrication collocated plant		Four existing BWR reactors		Repository		Lump-sum total for all facilities ($M)[a]
		Lump sum ($M)[a]	Annual ($M/year)[a]	Lump sum ($M)[a]	Annual ($M/year)[a]	Lump sum ($M)[a]	Annual ($M/year)[a]	Lump sum ($M)[a]	Annual ($M/year)[a]	
	Years of operation =	10		15.6		16.6 years for fee and trans-portation; 22.4 years for staff and capital replacements				
	"Preoperational" or "OPC" up-front costs:							No incremental cost impacts from MOX use		
1	R&D	89		21		36				146
2	NEPA, licensing, permitting	35		35		103				173
3	Conceptual design	7		2		1				10
4	QA, site qualification, S&S plans	5		1		2				8
5	Postconstruction startup	45		41		22				108
6	Risk contingency	34		0		0				34
	TOTAL OPC	$215		$100		$164		$0		$479
	"Capital" or "TEC" up-front costs (TEC):									
7	Title I, II, III engineering, design, and inspection	29		56		5				90
8a	Capital equipment	190		175		159				524
8b	Direct and indirect construction/modification	70		60		0				130
9	Construction management	16		0		0				16
10	Initial spares	4		14		0				18
11	AFI	76		45		0				121
12	Risk contingency	0		0		0				0
	TOTAL TEC	$385		$350		$164		$0		$899
	SUBTOTAL (INVESTMENT OR UP-FRONT COST) (TPC)	$600		$450		$328		$0		$1378

Note: combined PuP/MOX plant TPC is $1050M.

Table 4.28. LCC summary for all facilities in 24-category format for the four-BWR variant (cont.)

Category	Cost category description	PuP collocated plant		MOX fabrication collocated plant		Four existing BWR reactors		Repository		Lump-sum total for all facilities ($M)
		Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	
	PuP at LANL (halides)	$0		$0		$0		$0		0
	TOTAL UP-FRONT COST (TPC)	$600		$450		$328		$0		$1378
	Other LCCs:									
13	Operations and maintenance staffing	297	29.7	471	30.2	67	3.0			835
14	Consumables including utilities	83	8.3	432	27.7		0			515
15	Major capital replacements or upgrades	127	12.7	237	15.2	34	1.5			398
16	Waste handling and disposal	69	6.9	90	5.8		0			159
17	Oversight	10	1.0	16	1.0		0			26
18	M&O contractor fees	12	1.2	25	1.6		0			37
19	PILT to local communities	6	0.6	12	0.8		0			18
20	D&D	386		70		0				456
21	Revenues (if applicable) MOX or electricity	0		–2006	–128.6	0				–2006
22	Fees to privately owned facilities	0		0		482	29.0			482
23	Transportation of plutonium forms to facility	50	5.0	26	1.7	49	2.9			125
24	Storage of plutonium at existing 94-1 site facility	0								0
	PuP at LANL (halides)	1	0.1	0		0		0		1
	TOTAL OTHER LCC	$1041	$65.5	– $627	$84.0[b]	$632	$36.4[c]	$0	0	$1046
	GRAND TOTAL ALL LCC	$1641		– $177		$960		$0		$2424
	GRAND TOTAL LCC WITHOUT FEE	$1641		– $177		$478		$0		$1942

[a]All costs are in constant 1996 $M.
[b]Net annual cost after revenues would be –$44.6M/year.
[c]Applies only to first 16.6 years.

Table 4.29. Staffing for the four-BWR variant

	Collocated PuP/MOX	Reactors	Total
Direct FTEs	196	20	216
Indirect FTEs	574	20	594
Total FTEs	770	40	810

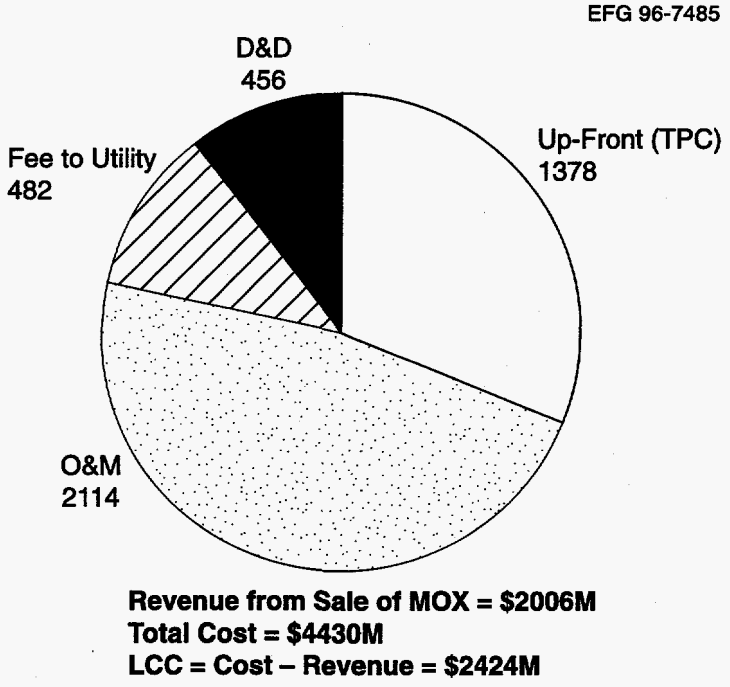


Figure 4.17. Summary of LCCs by major cost category

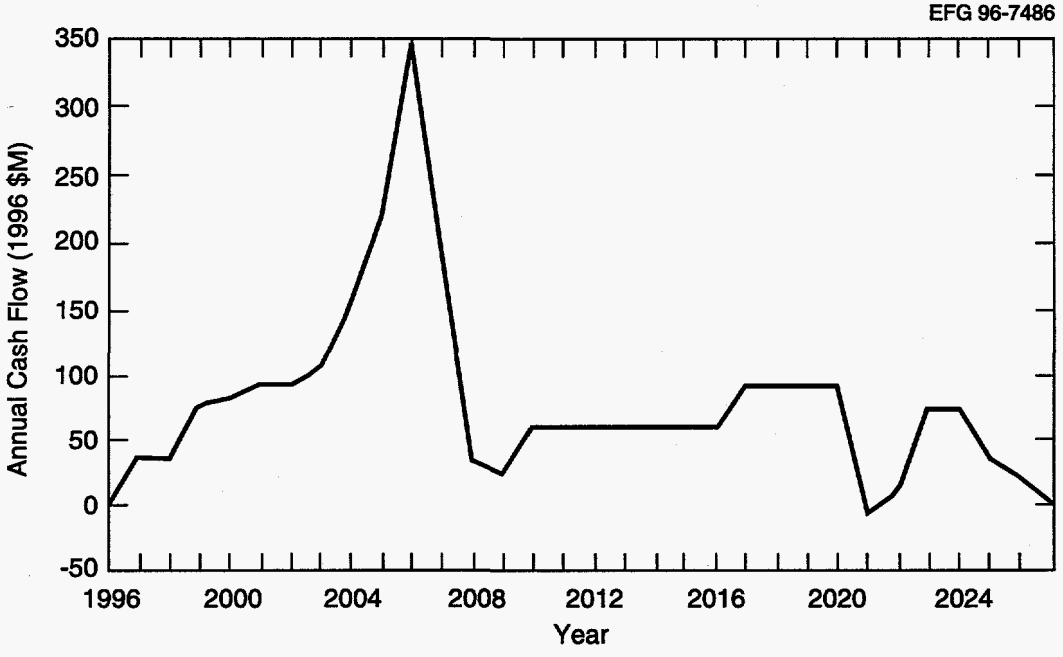


Figure 4.18. Annual constant dollar net cash flow from the U.S. government (after MOX sales revenues)

The cost analysis above includes the incentive fee, which was not in the TSR. Section H.4 of Appendix H shows how the LCCs in this chapter relate to those in Chap. 4 of the July 17, 1996, TSR.

4.5.3 Four-BWR Variant S&S Summary

There is no difference between the alternative with collocated PuP and MOX fuel fabrication facilities and the base case with two separate facilities with respect to S&S requirements. The analysis for the collocated facility assumes that, given the constraints of protecting restricted data, IAEA safeguards will be implemented on certain portions of the facility, including at least the MOX fuel fabrication areas. A determination must be made as to whether the IAEA will have access to the common use areas. The collocated facility will be under IAEA safeguards. The criteria for determining areas in this facility under the IAEA will be based on the safeguarding of restricted data. Those portions of the PuP facility that involve restricted data will not be subject to IAEA inspections until an acceptable inspection regime has been established that protects classified information.

The final disposition form for this variant meets the SFS. Both significant extrinsic (facility) and intrinsic (related to the material form) barriers exist. The existence of a collocated facility does not affect this alternative's ability to achieve the SFS.

The collocated facility helps accomplish a reduction of the number and duration of transport steps, which reduces risk. There are no intersite transportation requirements between the PuP and MOX fuel fabrication activities.

Table 4.30 shows the risk assessment for this alternative.

4.5.4 Four-BWR Variant Technical Viability Summary

The PuP facility is the least viable component of this alternative. This observation is not a deciding factor in alternative choice, because all alternatives must rely on this facility. Through fabrication technology is well known, an issue unique to this alternative is the requirement for the use of a burnable absorber that is intimately mixed with the fuel. Though this technology is in use with uranium fuels, use in mixed oxide fuels would require development or certification tests not required for other alternatives. Because the reactor operates with fuel having a fissile fraction similar to current uranium-based fuels and because the fuel cycle burnup is similar to existing extended burnup cycles, viability issues related to the reactor and repository are minor.

Table 4.30. Nonproliferation and S&S risk assessment for the four-BWR variant

	Cofunctional plutonium conversion and MOX fuel fabrication	Transit	Reactor	Transit	Repository
Threat					
Covert threat (domestic)	High/low	Low	Low/low	Low	Low
Overt threat (domestic	Medium-high/medium	Medium	Medium/low	Low	Low
Diversion (international)	High/medium	Medium	Medium/low	Low	Low
Risk against unauthorized parties					
Material form	High/medium	Medium	Medium/low	Low	Low
Environment	High/medium	Medium	Medium/medium	Medium	Medium/low
Safeguards and security	High/medium	Medium	Low/low	Low	Low
Risk against host nation					
Detectability	High/medium	Medium	Medium/low	Low	Low
Irreversibility	High/medium	Medium	Medium/low	Low	Low

The risk involved with this alternative is due, largely, to scheduling uncertainty. This, in turn, leads to an associated economic risk. All technologies are likely to be feasible, but integral burnable absorbers in MOX fuel are not currently used in the industry. This development area introduces some additional element of risk not present in other existing LWR alternatives. It is not conceivable that the program disposition goal is unattainable. However, the amount of development work required is unknown. The risk of not meeting the program goal increases, but by an unknown amount, if the development work is not pursued.

With the exception of integral burnable absorbers, all R&D items are concerned with assessment of fissile material throughput or provision of regulatory certification of the proposed fuel cycle. Throughput items include determination of process reliability and therefore throughput, process optimization to maximize throughput, and cost reduction.

4.5.5 Four-BWR Variant Transportation Summary

Multiple facilities are required for disposition of approximately 50 MT of excess weapons-usable plutonium as MOX fuel in four existing BWRs that have been converted to a MOX fuel cycle. Between each facility are a series of sequential movements of the plutonium from its present locations (storage vaults at a number of DOE facilities) through the various processing, fabrication, and reactor facilities, and ultimately, emplacement as spent fuel at an HLW repository. Figure 4.4 provides a simplified flowchart of the transportation segments associated with this existing LWR disposition alternative. Actual processing and fuel fabrication facility locations will be determined by DOE following the ROD. For analysis purposes, it has been assumed for this case that the excess plutonium is in interim storage at many locations within the DOE weapons complex. This material is first packaged and transported to a PuP facility (assumed for analysis purposes to be located in a new facility in the western United States),[2] where the material is converted to PuO_2. The PuO_2 is then repackaged and transported to a collocated MOX fuel fabrication facility plant (assumed for analysis purposes to be constructed on the same site as the PuP facility). Once fabricated, the fresh MOX fuel is packaged and transported to four existing BWRs that have been converted to a MOX fuel cycle. Spent fuel discharged from each reactor is first stored in spent fuel pools at each reactor for 10 years. Ultimately, the spent fuel is packaged and transported to an HLW repository for disposal in a geologic repository.

4.6 References

1. DOE Order 5633.3B, "Control and Accountability of Nuclear Materials."
2. General Electric, *Study of Plutonium Disposition Using Existing GE Boiling-Water Reactors*, NEDO-32361, "Appendix A, Full MOX Part II and Part IV."

5. Existing LWR Alternative: Quick Start Variant

5.1 Introduction

A review of the overall project schedule for the existing LWR base case (Chap. 2) reveals that although the reactors are predicted to be ready to load MOX fuel in early 2004, the domestic MOX fuel fabrication facility would not be ready to produce LUAs and mission fuel until early 2007. Thus, the reactors are ready to load the MOX fuel 3 years before it is available from the domestic fabrication facility. The Quick Start variant discussed in this chapter is designed to address this issue.

This variant is identical to the base-case LWR alternative (described in Chap. 2) except that the mission is accelerated by the use of existing European fuel fabrication facilities to fabricate early mission fuel before completion of the domestic MOX fuel fabrication facility.

Table 5.1 summarizes the facilities that would be used if this option were implemented. The top-level flow diagram, Fig. 5.1, depicts the major facilities in this variant (plutonium processing, European fuel fabrication facilities, domestic MOX fuel fabrication facilities, five PWRs, and the HLW repository) and the plutonium flow through them.

5.1.1 General Assumptions

All of the general assumptions made for the existing LWR base case apply to this Quick Start variation. Additionally, it is assumed that

- all international and domestic governmental and legal requirements are met in a timely fashion, and
- contracts with foreign companies are in place in time to support implementation of this alternative.

5.1.2 Summary Description of Quick Start Variant Disposition Facilities

The PuP, domestic MOX fabrication, reactor, and HLW repository facilities are identical to those discussed in Chap. 2 for the base-case alternative. However, this variant does take advantage of PuO_2 production by the ARIES demonstration and prototype operations and does require two additional facilities not needed for the purely domestic base-case alternative (Chap. 2). The first facility is the dedicated fuel storage facility used for receipt and temporary storage of fresh MOX fuel bundles from Europe. (A separate storage facility for the PuO_2 being shipped to Europe is not required because the SST shipments of this material are assumed to be loaded directly onto the transport vessels at the port of departure.) The second unique facility required is the European fuel fabrication facility.

PuP Facilities—The ARIES PuP technology expected to be employed for the plutonium disposition mission is currently under development at Los Alamos National Laboratory (LANL). It is anticipated that ~0.5 MT of PuO_2 will be available for the "demonstration" phase of the ARIES R&D program and that another 6.3 MT of PuO_2 will become available from the "prototype" phase of the R&D activities by 2003. This material is assumed to be available for early use in European fuel fabrication in the Quick Start option before startup of the full-scale PuP facility (which is identical to that previously described in Chap. 2).

EuroMOX Fuel Fabrication Facility—As discussed in Appendix A, it is anticipated that sufficient excess European fuel fabrication capacity will be available during the first decade of the next century to accommodate production of limited quantities of weapons-grade MOX fuel without requiring expansion of Europe's MOX fuel fabrication capacity beyond that

Table 5.1. Existing LWR Quick Start variant

Reactor type	Number	Ownership of reactor	Ownership of MOX fuel fabrication facility	Collocation of PuP and MOX fuel fabrication facility
PWR	5	Private	Private European/federal	No

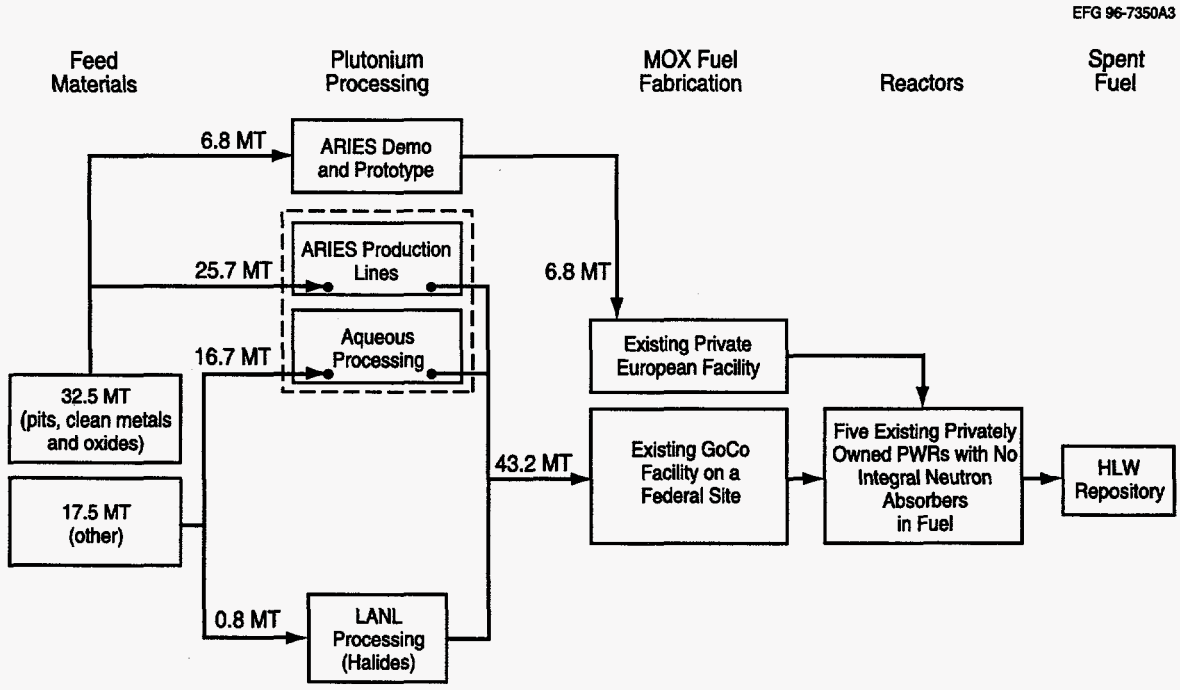


Figure 5.1. Top-level flow diagram for Quick Start variant

already planned. The Quick Start option takes advantage of this window of opportunity to obtain ~375 MOX fuel bundles for partial loading of five existing LWRs during their first three MOX irradiation cycles (~4.1 years) while the domestic fuel fabrication facility is being completed.

Fuel Storage Facility—This is a small fresh-fuel storage facility, assumed for the purposes of this analysis to be located on an east coast U.S. military base. Plutonium feed material awaiting shipment to Europe and fresh MOX fuel received from Europe would be temporarily stored in this facility while awaiting shipment to the reactor sites for loading into the reactors.

5.1.3 Description of Facility Interfaces for the Quick Start Disposition Variant

The facility interface issues for the Quick Start variant are most easily viewed in two phases: (1) the early U.S./European phase in which PuO_2 is shipped to Europe and completed fresh MOX fuel bundles are shipped back to the United States and (2) the second (domestic) phase in which European fuel fabrication is terminated and MOX fuel production commences in the United States fuel fabrication facility. These two phases are shown pictorially in Figs. 5.2 and 5.3.

During the first phase of the mission, PuO_2 is transported by SST to a U.S. coastal port for transport by special cargo ship to Europe (assumed for analysis purposes to be either BNFL's, COGEMA's, or Belgonucleaire's MOX fuel fabrication facility). Once fabricated, the fresh MOX fuel is packaged and returned to the U.S. coastal port, where it is received and stored temporarily while awaiting final transport via SSTs to the reactor sites. Following completion of the first phase of the mission, the facility interfaces and transport issues revert to those already discussed for the base-case alternative (Chap. 2), as depicted in Fig. 5.3.

Figure 5.4 depicts the PuO_2 production rate, the MOX fuel fabrication rate, and the fuel loading schedule for the reactors; and Fig. 5.5 displays the MOX fuel production schedule, the reactor loading schedule, and the schedule for shipping spent fuel to the repository. (For the sake of simplicity, it has been assumed for this analysis that the European fuel fabrication commences with the lead test assemblies and continues uninterrupted until the first 375 mission fuel assemblies have been fabricated.).

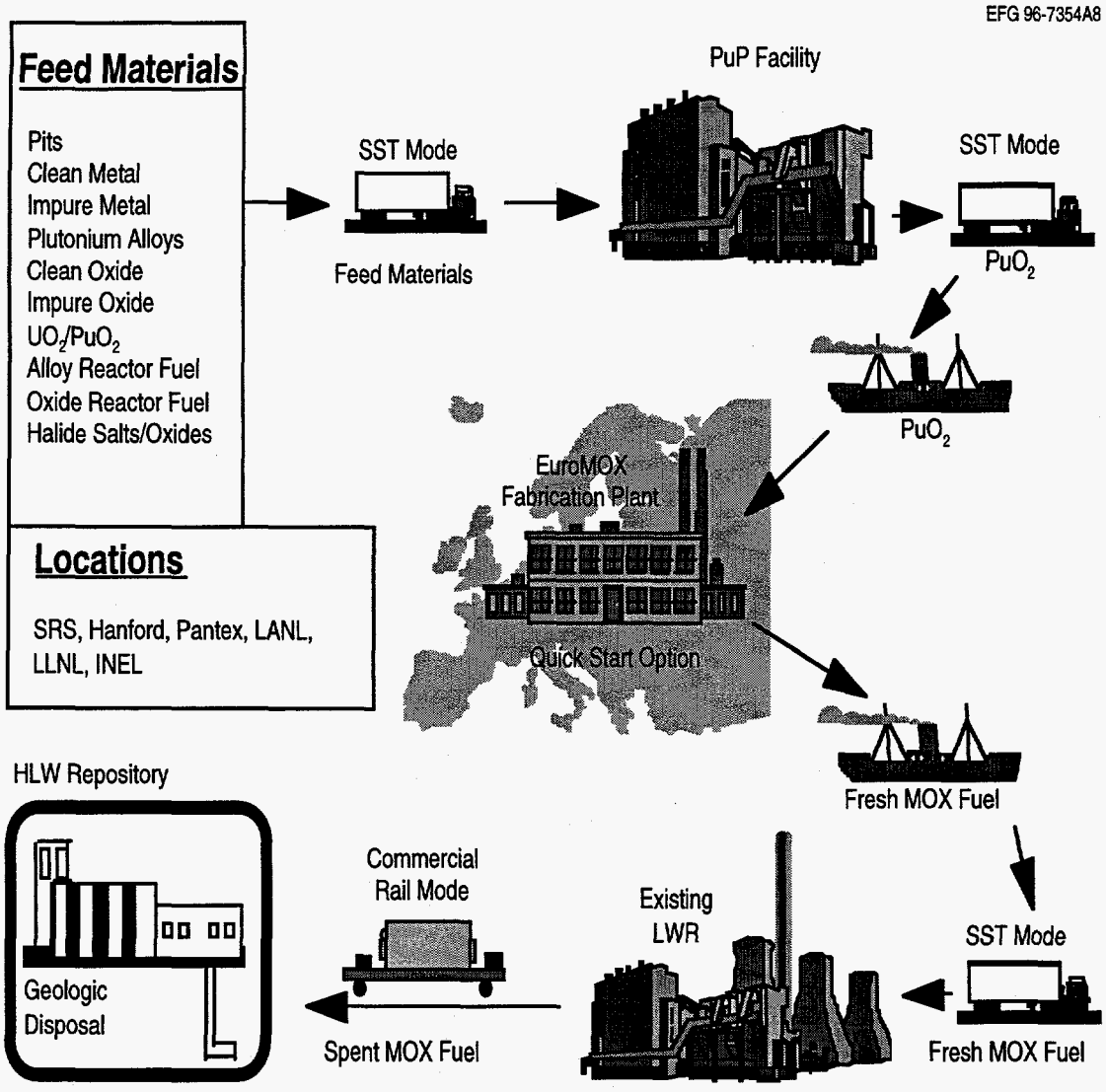


Figure 5.2. Simplified flowchart showing transportation segments for the European phase of the Quick Start variant

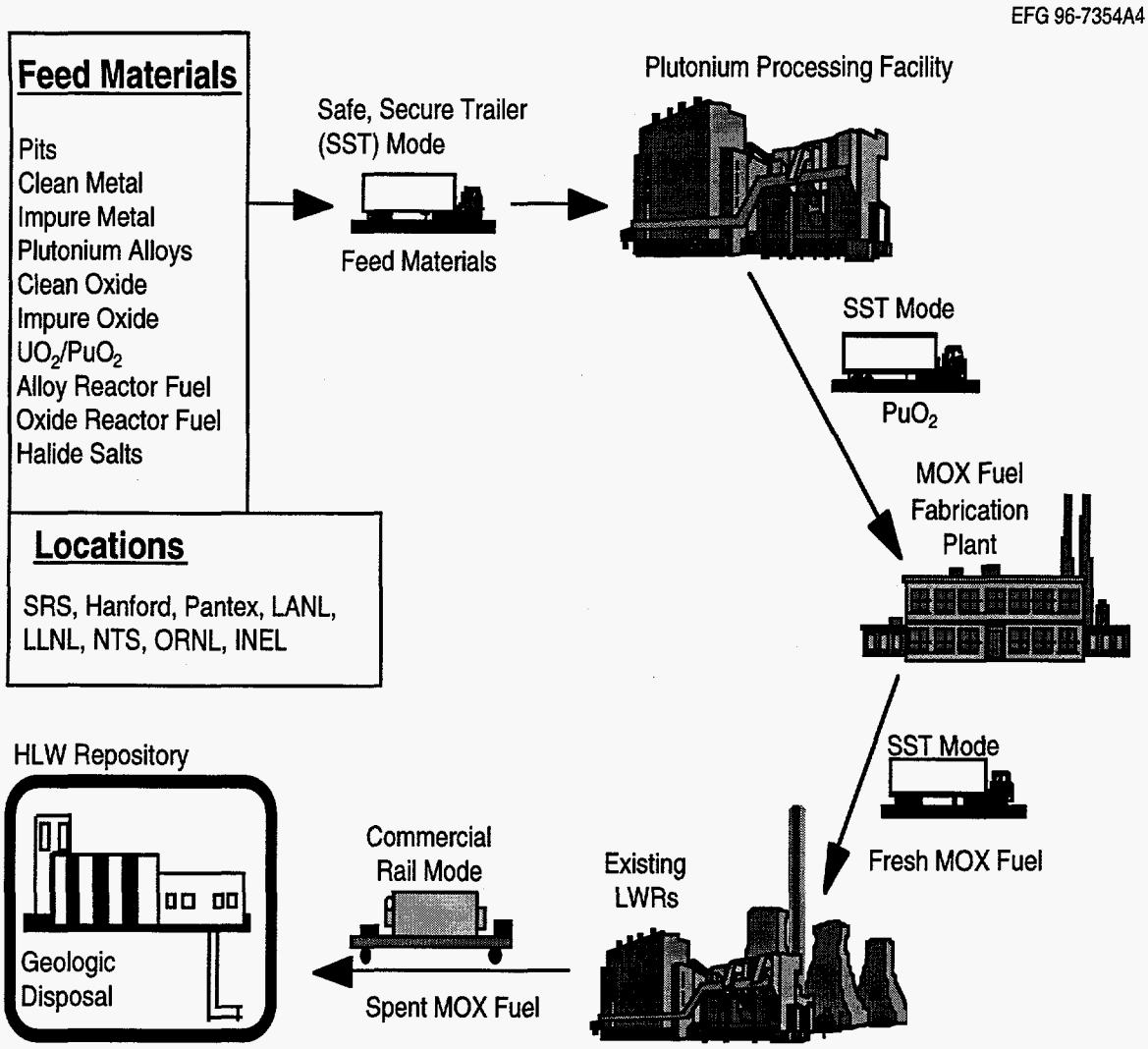


Figure 5.3. Simplified flowchart showing transportation segments for the domestic phase of the Quick Start variant

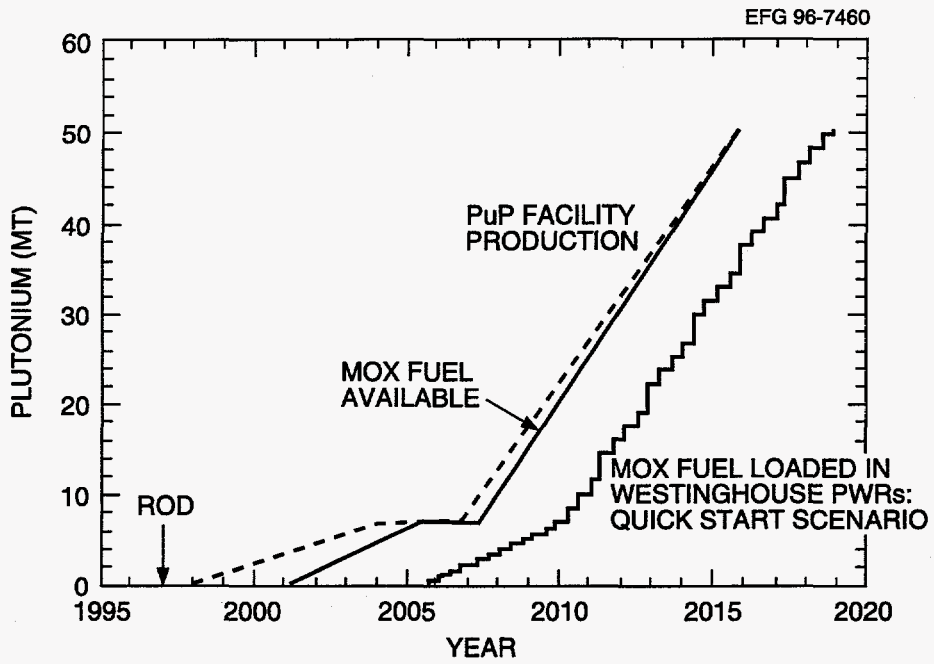


Figure 5.4. Plutonium dispositioning schedule

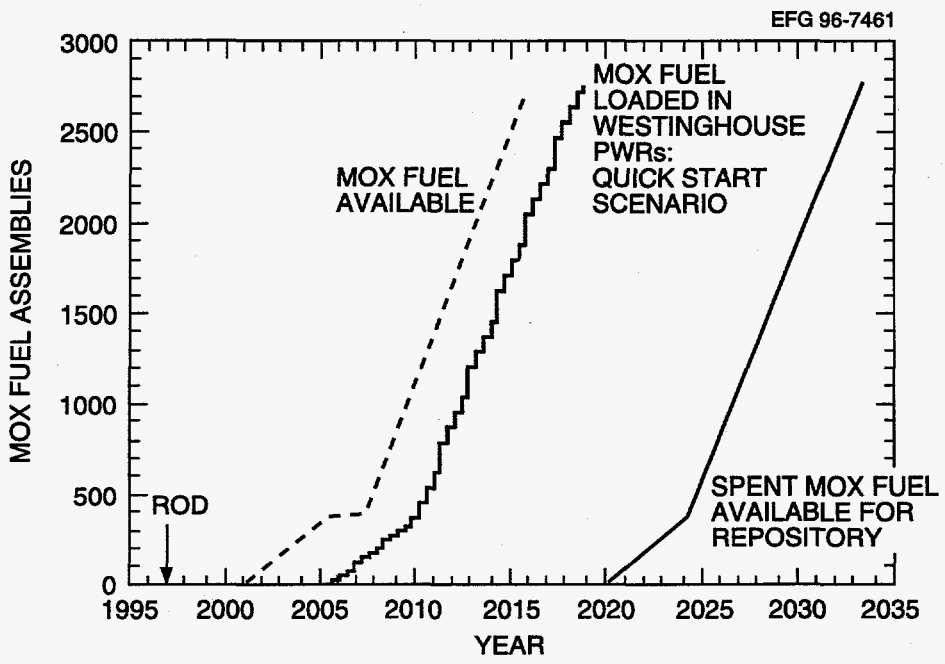


Figure 5.5. MOX fuel assembly processing schedule

5.2 PuP Facility

5.2.1 PuP Facility Description

The PuP production facility for this variant is identical to the PuP facility for the base case. Refer to Chap. 2 for the description of the PuP facility and technical viability discussion.

5.2.2 PuP Facility Design and Construction

5.2.2.1 PuP Facility Design and Construction Schedule

The PuP facility design and construction schedule for this alternative is the same as described in Chap. 2, Sect. 2.2.2 and Table 2.2.

5.2.2.2 PuP Facility Design and Construction Cost

The PuP facility design and construction costs are the same as those for the five-LWR base case in Table 2.3. No costs are assessed in this category for the ARIES demonstration and prototype operations that produce the 68 MT of PuO_2 at LANL. The TEC (sum of LCC categories 7–12) totals $171M (Table 5.2).

5.2.3 PuP Facility Oversight and Permitting

5.2.3.1 PuP Facility Oversight and Permitting Schedule

The PuP facility oversight and permitting schedule for this alternative is the same as described in Chap. 2, Sect. 2.2.3 and Table 2.4.

5.2.3.2 PuP Operations-Funded Project Cost

The PuP operations-funded project cost (OPC) shown in categories 1–6 of Table 5.2 includes several categories of costs in addition to licensing and permitting. The OPC is the same as that for the five-LWR base case (Tables 2.5 and 2.10) except that only $40M for R&D is shown in category 1. The remaining $41M that was allocated in this category for the base case has been shifted in the Quick Smart variant to a special R&D account in category L-1 of Table 5.2. The $57M cost allocation of category L-1 includes this $41M plus an additional $16M for operation of the ARIES demonstration and prototype facilities at LANL. Thus, the effective OPC for the Quick Start PuP operation is the sum of the calculated OPC from Table 5.2 ($110M) and category L-1 ($57M) or a total of $167M. This cost compares with the $151M total OPC of the base case presented in Tables 2.5 and 2.10. When the $171M TEC from Table 5.2 is added to this effective OPC, the overall investment cost (TPC) for the Quick Start plutonium processing is $338M compared with $322M for the base case.

5.2.4 PuP Facility Operations

5.2.4.1 PuP Facility Shipment and Storage

The surplus plutonium feed materials will be packaged and transported from their present locations to the PuP facilities where they will be converted to PuO_2. Once in oxide form, the material will be repackaged and stored in vaults until it is needed by the MOX fuel fabrication facilities. With the exception of the early shipments of material to and from the ARIES prototype facility, the plutonium shipment and storage issues for this option are the same as those described in Chap. 2 for the base-case existing LWR option.

5.2.4.2 PuP Facility Operations Process

The domestic PuP facility operations are the same as those described in Chap. 2, Sect. 2.2.4.2.

5.2.4.3 PuP Facility and Prototype Operations Schedule

The ARIES prototype is scheduled to begin operation in January 1998 and will operate for 6 years (Table 5.3). A sufficient amount of PuO_2 will be available for shipment to the EuroMOX fuel fabrication facility in July 1999.

The PuP facility is scheduled to begin operations in July 2007 and will operate for 8.5 years with an annual plutonium throughput of 5 MT. The first PuO_2 will be available for shipment 2 months after the start of operation. The operational schedule is shown in Table 5.3 and as a part of Sect. 5.2.6, and the schedule summary is shown in Table 5.4.

5.2.4.4 PuP Facility Operations Cost

The annual SRS PuP facility operations cost is $88.7M/year (excluding transportation costs), which is

Table 5.2. Plutonium processing LCCs in 24-category format

Category	Cost category description	Plutonium processing at SRS and LANL	
		Lump sum ($M)	Annual ($M/year)
	Years of SRS operation = 8.5 years for 42.4 MT of plutonium; ARIES demonstration and prototype process 6.8 MT of plutonium; LANL processes 0.8 MT of halides		
	Preoperational or OPC part of up-front cost		
	Up-front costs:		
1	R&D (SRS portion, $41M of LANL R&D in line L-1 below)	40	
2	NEPA, licensing, permitting	6	
3	Conceptual design	3	
4	QA, site qualification, S&S plans	0	
5	Postconstruction startup	50	
6	Risk contingency	11	
	TOTAL SRS OPC	$110	
	Capital or TEC part of up-front cost		
7	Title I, II, III engineering, design, and inspection	17	
8a	Capital equipment	34	
8b	Direct and indirect construction/modification	32	
9	Construction management	4	
10	Initial spares	3	
11	AFI (percentage of categories 7–10)	25	
12	Risk Contingency	56	
	TOTAL SRS TEC	$171	
	SUBTOTAL SRS UP-FRONT COST	$281	
L-1	Total up-front costs for PuP at LANL (ARIES demonstration and prototype)	$57	
	TOTAL UP-FRONT COST (TPC)	$338	
	Other LCCs (years of PuP facility operations): 9.22		
13	Operations and maintenance staffing	595	70.0
14	Consumables including utilities	72	8.5
15	Major capital replacements or upgrades (included in category 14)	0	0
16	Waste handling and disposal	56	6.6
17	Oversight	9	1.0
18	M&O contractor fees	15	1.7
19	Payments-in-lieu-of-taxes to local governments	7	0.9
	TOTAL SRS RECURRING COST	$754	$88.7
20	D&D	169	
21	Revenues (if applicable) from sale of MOX or electricity	0	
22	Fees to privately owned facility	0	
23	Transportation of plutonium forms to facilities (14.5-year total for SRS and LANL)	35	2.4
24	Storage of plutonium at existing 94-1 site facility		
L-2	Other LCCs for plutonium processing at LANL (halides, ARIES prototype)	91	15.2[a]
	TOTAL OTHER LCC	$1049	*b*
	GRAND TOTAL ALL LCC (1996 $M)	$1387	

[a]ARIES prototype recurring costs distributed over 6 years, halide processing over 10 years.

[b]No total calculated because some PuP activities are not concurrent.

Table 5.3. PuP facility and prototype operational schedule

Task name	Duration (months)	Start	Finish
ARIES Demonstration and Prototype	99	10/1995	1/2004
Set Up ARIES Demonstration	9	10/1995	7/1996
ARIES Demonstration	18	7/1996	1/1998
ARIES Prototype Operation	72	1/1998	1/2004
Sufficient PuO_2 for shipment	18	1/1998	7/1999
Preoperational Phase	12	8/2005	7/2006
Operation	109	7/2006	8/2015
Approval to Commence Operation (KD-4)			7/2006
Plutonium Processing Duration	109	7/2006	8/2015
First PuO_2 Available	2	7/2006	9/2006

Table 5.4. PuP facility schedule summary

Task name	Duration (months)	Start	Finish
R&D Funding Available			10/1995
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
ARIES Prototype Setup & Operation	99	10/1995	1/2004
Site and Facility Selection	12	12/1996	12/1997
Oversight and Permitting	60	12/1996	12/2001
Design Process	61	12/1996	1/2002
Facility Modification	48	1/2002	1/2006
Preoperational Phase	12	8/2005	7/2006
Operation	109	7/2006	8/2015
D&D	24	9/2015	9/2017

the same as the base case cost. Because of the preproduction of 6.8 MT of PuO_2 in the ARIES demonstration and prototype, however, the PuP facility needs to run for ~8.5 years instead of 10 to finish the processing of the remaining 43.2 MT of plutonium. The operations costs for the ARIES demonstration are embedded in the OPC category discussed previously. The operations cost for the ARIES prototype is $15M/year for 6 years ($90M lump sum) and is shown in Table 5.5 and is included in line L-2 in Table 5.2. As with the other reactor cases, 0.8 MT of plutonium halide materials would be processed at LANL, with an associated total operations cost of $1.4M. Thus, the total operations cost of the LANL plutonium processing operations (category L-2 in Table 5.2) is $91M. Use of ARIES preproduction slightly reduces the total LCC cost increment to the PuP facility alone ($1387M vs $1414M in the base case).This cost savings is primarily created by the reduced operating period of the SRS plutonium processing facility (8.5 years instead of 10 years).

Table 5.5. Sources of PuO_2 and their LCCs for the Quick Start variant

Source of PuO_2	Costs (constant 1996 $M)					Total plutonium processed (MT cumulative)	Years of operation
	Up-front cost (capital and OPC) ($M)	Average annual operations ($M/year)	Operations total ($M)	D&D ($M)	Total LCC ($M)		
Halide processing at LANL	0	0.14	1.4[a]	0	1.4	0.8	10
ARIES demonstration at LANL (0.1 MT in 1996; 0.4 MT in 1997)	28[b]		Included in OPC	0	28	0.5	2
ARIES prototype at LANL (~1.05 MT/year starting in 1998)	29[b]	15.0	90[a]	0	119	6.3	6
PuP facility at SRS: HYDOX lines in NSR at SRS + aqueous (5 MT per year in 2007 to end 8.5 years of campaign)	281 (includes $40M of SRS R&D)	88.7	754	169	1204	42.4	8.5[c]
Transportation from 94-1 sites to SRS or LANL	0	2.4[d]	35[e]	0	35		14.5
Totals for plutonium processing	$338	*f*	$880	$169	$1387	50.0	

Note: A few metric tons of clean metal plutonium from EM canyon operations at SRS may be available for use in Quick Start (in addition to 50 MT of plutonium)

[a]These two operations sum (in dollars rounded to the nearest $M) to the $91M sum shown on line L-2 of Table 5.2.

[b]These two up-front costs total to $57M, as shown on line L-1 of Table 5.2. Of this $57M, $41M represents LANL R&D costs that would have been expended even if no Quick Start option were invoked (i.e., the base case in Chap. 2). The $16M difference represents extra R&D funding needed for production operation at LANL.

[c]The PuP design throughput of 5 MT plutonium/year can accommodate 42.4 MT plutonium in 8.5 years. The annual recurring costs for the PuP are the same as for the base-case PuP facility in Chap. 2.

[d]Transportation cost averaged over 14.5 years of operations (8.5 for PuP facility, 6.0 for LANL ARIES prototype).

[e]Transportation costs include SST transport of the plutonium forms from 94-1 sites to both the SRS PuP facility and to LANL.

[f]Not applicable, because annual costs are not incurred over comparable time frames.

5.2.5 PuP Facility D&D

5.2.5.1. PuP Facility D&D Schedule

The PuP facility D&D schedule (Table 5.4) for this alternative is the same as described in Sect. 2.2.5.1.

5.2.5.2 PuP Facility D&D Cost

The value of $169M (category 20 in Table 5.2) for D&D of the PuP facility is the same as for the base case. The D&D costs for the ARIES demonstration and prototype are imbedded in the OPC category 1 and L-1 R&D costs.

5.2.6 PuP Facility and Prototype Schedule Summary

The overall PuP facility and prototype implementation schedule is summarized in Table 5.4 and shown in Fig. 5.6. This schedule does not include any contingency for schedule delays because of site selection difficulties, redesign, construction delays, or a delay in the approval of line item funding.

The critical path for the development of this facility is through the design and construction process. If any of these tasks are delayed in their schedule, the rest of the implementation process will also be delayed. This critical path is shown in Fig. 5.6. If the start of operations at the PuP facility is delayed more than 3 months, the start of operations at the MOX fuel fabrication facility will also be delayed because the PuO_2 will not be available to begin fuel fabrication at the domestic fuel fabrication facility. Similarly, if the ARIES prototype operation is delayed more than a year, or its output is lower than expected, there may not be sufficient PuO_2 to ship to Europe to begin the early fuel fabrication.

5.2.7 PuP Facility Cost Summary

Table 5.2 shows the PuP facility LCCs in the 24-category format with additional rows added to cover the ARIES demonstration and prototype preproduction and LANL halide processing LCCs. Thus, use of the ARIES demonstration and prototype facilities for PuO_2 production produces an LCC savings of $27M ($1387M vs $1414M for the base case).

5.2.8 PuP Facility S&S Summary

The inherent risks associated with the PuP facility should be no different than for the base case. A more detailed S&S assessment of ARIES and prototype operations would be needed. Because classified components may be involved in the front-end activities of this facility, international safeguards could not be implemented until agreements have been made ensuring protection of restricted data.

5.3 MOX Fuel Fabrication Facility

5.3.1 MOX Fuel Fabrication Facility Description

As previously stated, this variant assumes the use of an existing European fuel fabrication facility for fabrication of the first LUAs and the first 375 mission fuel bundles, and a new domestic fuel fabrication facility for the production of all remaining fuel.

The domestic MOX fuel fabrication facility for this variant is identical to the MOX fuel fabrication facility for the base case. Refer to Chap. 2 for the description of the domestic MOX fuel fabrication facility and technical viability discussion.

5.3.2 MOX Fuel Fabrication Facility Design and Construction

5.3.2.1 MOX Fuel Fabrication Facility Design and Construction Schedule

The domestic MOX fuel fabrication facility design and construction schedule for this variant is the same as described in Chap. 2, Sect. 2.3.2.1.

5.3.2.2 MOX Fuel Fabrication Facility Design and Construction Cost

The domestic MOX fuel fabrication facility for the Quick Start variant is essentially the same 118-MTHM/year facility as in the five-LWR base case. Because 6.8 MT of the 50-MT plutonium total is fabricated into MOX fuel in Europe, the domestic plant handles only 43.2 MT of plutonium during its life. The

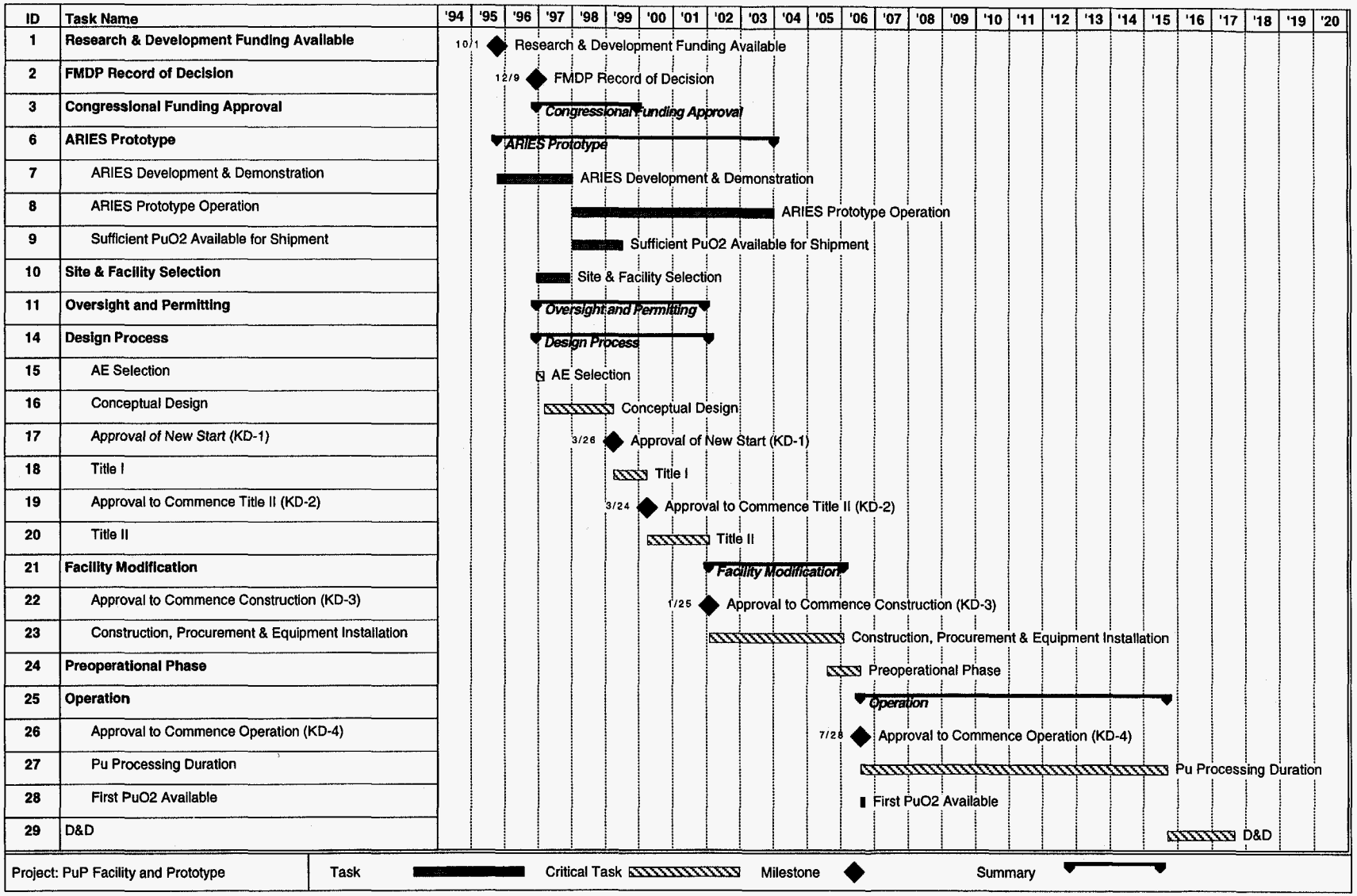


Figure 5.6. PuP facility and prototype schedule summary

TEC of $310M for this facility (Table 5.6) is made up of the base $300M for the MOX fuel fabrication in an existing facility (Table 2.14) plus $10M for a MOX bundle storage facility at an East Coast port to store the fabricated fuel shipped by sea from the European fabricator.

5.3.3 MOX Fuel Fabrication Facility Licensing and Permitting

A clear path forward is provided in the existing regulations promulgated by the NRC with regard to obtaining the special license required for the domestic fabrication of MOX fuel (discussed in Chap. 2), or for export of SNM and source material needed to fabricate MOX fuel abroad under the "Quick Start" option. Importing the finished product of MOX fuel assemblies back into the United States falls under the provisions of a general license under NRC regulations that permit importing such material to any facility that is licensed to possess that material. Because the Euro-MOX fuel fabrication facility is outside the United States, other environmental permitting requirements under U.S. law apply only to the extent of and within the context of applicable bilateral agreements between the United States and the government of the country in which the facility resides or to the extent that environmental laws of the United States can be interpreted to apply in transboundary situations. The licensing and permitting approach for the reactor-based plutonium disposition options is to satisfy the NAS ES&H criteria "that any disposition option to operate in the United States:

- should comply with United States regulations governing allowable emissions of radioactivity to the environment, and allowable radiation doses to workers and the public, from civilian nuclear-energy activities;
- should comply with international agreements and standards covering the disposition of radioactive materials in the environment; and
- should not add significantly to the ES&H burdens that would be expected to arise, in the absence of weapons-usable plutonium disposition, from appropriate management of the environmental legacy of past nuclear-weapons production and from appropriate management of the ES&H aspects of past and future nuclear-energy generation."

Because the foreign MOX fuel fabrication facility does not involve operations at a facility within the United States, the licensing and permitting requirements of the cognizant foreign government agencies will be applied to ensure nuclear safety and environmental protection during facility operations and for waste handling and disposal. However, it is currently assumed that plutonium-bearing radioactive wastes will be returned to the United States for disposal. The U.S. licensing of the PuO_2 and source material exports and MOX fuel import will be conducted under 10 CFR 110. Because it is assumed that plutonium-bearing radioactive wastes generated during MOX production and fuel fabrication are to be returned to the United States for disposal, this too will be conducted under 10 CFR 110.

National Environmental Policy Act (NEPA)—The decision on whether to prepare an option-specific EIS with regard to the use of a foreign MOX fuel fabrication facility licensed by a foreign government will be made consistent with the provisions and conditions specified in Appendix B to Subpart D of 10 CFR 1021 and in Sect. 2 of Presidential Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*, January 4, 1979. An option-specific EIS should address any transboundary issues identified in applicable bilateral agreements relating to relevant environmental issues and obligations under international law relating to transboundary pollution and environmental quality.

Currently, for export and import licenses, the NRC regulations in 10 CFR 51.1 exempt export licensing under 10 CFR 100 from the NRC NEPA regulations of 10 CFR 51, because the environmental impacts of such exports based on the uranium fuel cycle were addressed in the *Final Environmental Statement: U.S. Nuclear Power Export Activities*, ERDA-1542, April 1976.

Therefore, no environmental report is required to be submitted under 10 CFR 110.31 and 110.32, nor are there NRC review criteria for such in 10 CFR 100.40 and 110.42. A hearing request or intervention petition is allowed under 10 CFR 100.82, and the Commission has reserved the right of discretion in addressing environmental matters as discussed in 10 CFR 51.20(a)(2). Therefore, action by the NRC to address NEPA either for the export of SNM and source materials or for the import of MOX fuel and associated radioactive wastes is possible but is assumed not to be likely under NRC regulations, unless, in the judgment of the Commission, an intervenor introduces significant new information or issues that have not been addressed adequately in the PEIS or in an option-specific EIS.

Table 5.6. MOX fabrication LCCs in 24-category format

Category	Cost category description	Eurofab and U.S. MOX plant[a]	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 8.5 for U.S. plant; 4.1 years for Eurofab		
	Preoperational or OPC		
	Up-front costs:		
1	R&D	21	
2	NEPA, licensing, permitting	35	
3	Conceptual design	2	
4	QA, site qualification, S&S plans	1	
5	Postconstruction startup	41	
6	Risk contingency	0	
	SUBTOTAL OPC	$100	
	Capital or TEC part of up-front cost		
7	Title I, II, III engineering, design, and inspection	48	
8a	Capital equipment	150	
8b	Direct and indirect construction/modification	51	
9	Construction management (in category 8b)	0	
10	Initial spares	12	
11	AFI (percentage of categories 7–10)	39	
12	Risk contingency	0	
	SUBTOTAL TEC	$300	
	STORAGE FACILITY AT EAST COAST PORT	$10	
	TOTAL TEC	$310	
	TOTAL UP-FRONT COST (TPC)	$410	
	Other LCCs (years of operations):		
13	Operations and maintenance staffing	282	33.1
14	Consumables including utilities	279	32.8
15	Major capital replacements or upgrades	147	17.3
16	Waste handling and disposal	59	6.9
17	Oversight	9	1.0
18	M&O contractor fees	16	1.8
19	Payments-in-lieu-of-taxes to local communities	8	0.9
	TOTAL ANNUAL RECURRING COSTS	$800	$93.8
20	D&D (percentage of capital or dollar estimate)	60	
21	Revenues (if applicable) MOX or electricity	–1387	–110.1[b]
22	Government fees to privately owned facility (Eurofab)	237	57.8[c]
23	Transportation of plutonium forms to facility	26	2.1[d]
24	Storage of plutonium at existing 94-1 site facility	N/A	
	TOTAL OTHER LCC	–$264	$82.3[e]
	GRAND TOTAL ALL LCC (1996 $M)	$146[f]	

[a]U.S. MOX plant throughput is 118 MTHM/year.
[b]Received over 12.6 years.
[c]Paid over 4.1 years.
[d]Paid over 12.6 years.
[e]Weighted average annual cost for U.S. and European MOX; no revenue included.
[f]Total LCC before revenues is $1533M.

Atomic Energy Act of 1954, as amended, and related legislation—Sections 54 and 57 and Title XI, Sects. 121 through 132, of *the Atomic Energy Act of 1954*, as amended, apply to the export of PuO_2 and source materials that would be used for MOX fuel fabrication abroad as well as to the import of the MOX in fabricated fuel assemblies. The licensing requirements for the export of PuO_2 and source materials are addressed in 10 CFR 110. These regulations require both a Commission review (10 CFR 100.40) and an Executive Branch review (10 CFR 100.41) of the licensing application. The Executive Branch is required to confirm that the proposed license complies with the terms of an agreement for cooperation executed under Sect. 123 of the Act with the government of the country in which the MOX fuel fabrication facility is located.

The import of the fabricated MOX assemblies back into the United States will be done under a general license under 10 CFR 110.27(a), which requires only that the recipient be licensed to possess the materials being received. In this case, the recipient is the DOE-contracted owner/operator of the commercial nuclear reactor with a license amendment to allow the possession and utilization of MOX fuel for purposes of plutonium disposition. At the time of import, the licensee only needs to have the appropriate licenses under 10 CFR 40 and 70 for possessing the MOX fuel, because the amendment to the utilization license under 10 CFR 50 may still be in the NRC review process.

The import of radioactive wastes generated in the MOX fabrication is authorized under a general license in 10 CFR 110.27(c) only if the U.S. government is the recipient. Such would be the case if the decision were made to place such wastes in a DOE facility such as WIPP in New Mexico. If DOE places a contract with a commercial firm to receive, process, or dispose of these wastes, a specific license for import is required with the license application containing information about the radioactive wastes as required in 10 CFR 100.32(f)(5), (6), and (7). As in the case of a specific export license as described previously, the regulations for a specific import license for radioactive wastes require both a Commission review (10 CFR 110.40) and an Executive Branch review (10 CFR 100.41) of the licensing application.

The transportation of exported and imported materials and of imported wastes will be done in accordance with NRC regulations in 10 CFR 71, DOT regulations in 49 CFR 171–179, and, where appropriate, EPA regulations in 40 CFR 263. Safeguards regulations in 10 CFR 73 apply to transportation of SNM.

Resource Conservation and Recovery Act (RCRA)—RCRA will apply only to wastes generated in the operation of the foreign MOX fuel fabrication facility to the extent of applicable provisions in bilateral transitional agreements, to the extent that environmental laws of the United States can be interpreted to apply in transboundary situations, or if the wastes are to be returned to the United States for final processing and disposal. The applicability of RCRA provisions would be subject to detailed review in an option-specific EIS. However, because the plutonium disposition mission is a DOE-supported program, all facets of it are subject to the waste minimization/pollution prevention policies of the President and the Secretary of Energy with regard to the plans required of waste generators under Sect. 3002(b) of RCRA. As determined appropriate by the United States and affected foreign governments, such waste minimization/pollution prevention plans will be negotiated within the agreement on cooperation.

Clean Air Act and Clean Water Act—These laws will only apply to the operation of the MOX fuel fabrication facility to the extent of applicable provisions in bilateral transitional agreements between the United States and the affected foreign government or to the extent that the environmental laws of the United States can be interpreted to apply in transboundary situations. The applicability of these laws would be subject to a detailed review in an option-specific EIS.

5.3.3.1 MOX Fuel Fabrication Activities Licensing and Permitting Schedule

The MOX fuel fabrication facility licensing and permitting schedule for this alternative is the same as described in Chap. 2 (Table 2.15).

The contract negotiations with the European fuel fabricators and the licensing and permitting requirements for shipping PuO_2 to Europe are estimated to require 16 months and will begin after approval of the intermediate line item funding.

5.3.3.2 MOX Fuel Fabrication Facility Operations-Funded Project Cost

The OPCs for the domestic MOX fuel fabrication facility are the same as for the five-LWR base case ($100M) (Table 2.16).

5.3.4 MOX Fuel Fabrication Facility Operations

5.3.4.1 MOX Fuel Fabrication Facility Shipments and Storage

After plutonium is converted to PuO_2, the PuO_2 will be repackaged (in many of the packages described in Appendix G) and shipped to the MOX fuel fabrication facility.

During the initial phase of this variant, the PuO_2 is packaged and shipped via SST to a U.S. coastal port, where the packages are loaded into standard ISO cargo containers (each holding 28 packages). A total of 18 ISO containers is loaded into each ship for the voyage to Europe.

The domestic fuel fabrication facility will operate on a schedule similar to the existing LWR operation schedule (~10 years). This may require that some of the PuO_2 be placed in a lead storage vault because the shipment campaign will also be completed in ~10 years. The lead storage vault could be accommodated in the design of the MOX fuel fabrication facility, or DOE could choose to use excess vault capacity at another DOE site.

Shipment Information—Tables 5.7 and 5.8 summarize estimates of the number of packages and shipments required for the SST and oceangoing aspects of this shipment leg, respectively. Each SST will transport approximately 28 packages with approximately three SSTs per convoy.

Table 5.7. Parameters for PuO_2 transport leg (SST shipments)

	Quantity plutonium/ campaign (MT)	Estimated number of packages to be shipped	Number of SST shipments/ campaign
4.5 kg Quick Start (assuming 3.3 kg/ package	6.8	2,060	74
4.5 kg Domestic (assuming 1.5 kg/ package)	43.2	28,940	1,034

Table 5.8. Parameters for PuO_2 transport leg (ocean shipments)

Maximum material/ package	Quantity plutonium/ campaign (MT)	Estimated number of packages to be shipped	Number of ocean shipments/ campaign
4.5 kg Quick Start (assuming 3.3 kg/ package)	6.8	2060	5

5.3.4.2 MOX Fuel Fabrication Facility Operations Process

The domestic MOX fuel fabrication process is as described in Chap. 2, Sect. 2.3.4.2.

5.3.4.3 MOX Fuel Fabrication Activities Operations Schedule

MOX fuel fabrication will begin in Europe as soon as the first PuO_2 arrives in June 2000. After fabrication of the LUAs, the European fuel fabrication facility will fabricate 85 assemblies per year, with an annual plutonium throughput of 1.5 MT, for 4.4 years and a total of 375 assemblies.

The preoperational checkout of the domestic facility starts as soon as the construction is complete and will require 2 years. The LUAs will be ready to load into the first reactor 6 months after the start of operations at the MOX fuel fabrication facility. Following this startup period, the MOX fuel fabrication facility will operate for 8.5 years with an annual plutonium throughput rate of 5 MT to supply fuel for the five existing PWRs at the specified loading rate. This throughput assumes an annual output of 280 assemblies for a total of 2381 assemblies. The operational schedule is shown in Table 5.9 and as a part of Sect. 5.3.6.

5.3.4.4 MOX Fuel Fabrication Facility Operations Cost

The annual operations cost of $93.8/year for the 118 MTHM/year domestic MOX fuel fabrication facility is the same as for the base case (Table 5.6). Because the plant processes only 43.2 MT of plutonium (1005 MTHM) instead of 50 MT of plutonium

Table 5.9. MOX fuel fabrication facility operational schedule

Task name	Duration (months)	Start	Finish
European Facility Interactions	80	12/1998	8/2005
Contract Negotiation and Approval	16	12/1998	4/2000
Initial PuO_2 Shipment to Europe	2	4/2000	6/2000
Fabrication of LUAs	9	6/2000	3/2001
LUA Shipment from Europe	2	3/2001	6/2001
Mission Fuel Fabrication	53	3/2001	8/2005
Initial Mission Fuel Shipped from Europe	2	3/2001	6/2001
Domestic MOX Fuel Fabrication Facility Operations	132	12/2004	12/2015
Preoperational Phase	24	12/2004	12/2006
PuP Facility Complete			9/2006
MOX Fuel Fabrication Facility Ready for PuO_2			12/2006
Operation	108	12/2006	12/2015
MOX Facility Operation Start			12/2006
LUA Fabrication	6	12/2006	6/2007
MOX Fuel Fabrication	102	6/2007	12/2015

(1163 MTHM) during its life, it will operate for 8.5 years instead of 9.8 years. Therefore, operations costs for 1.3 years are avoided.

Costs for transporting the PuO_2 to the European fabricators assume safe and secure transport by sea. The analysis assumes that the European fabricators charge $1500/kgHM for fabricated MOX bundles made from clean PuO_2. (This price represents the midrange of MOX fabrication unit price estimates mentioned in the literature and trade press.) The $237M cost for this service (category 22 in Table 5.6) assumes that 158 MTHM of MOX are produced in Europe at this price. It is assumed that all MOX fuel is sold to the LWR utility owners at the LEU equivalent price of $1193/kgHM as in the base case. The total MOX revenue (or fuel displacement credit) of $1387M (category 21 in Table 5.6) is the same as for the base case.

5.3.5 MOX Fuel Fabrication Facility D&D

5.3.5.1 MOX Fuel Fabrication Facility D&D Schedule

The MOX fuel fabrication facility D&D schedule for this alternative is the same as described in Chap. 2, Sect. 2.3.5.1.

5.3.5.2 MOX Fuel Fabrication Facility D&D Cost

The D&D cost of $60M for the MOX fuel fabrication facility is the same as for the LWR base case discussed in Chap. 2, Sect. 2.3.5.2.

5.3.6 MOX Fuel Fabrication Facility Schedule Summary

The overall MOX fuel fabrication activities schedule is summarized in Table 5.10 and shown in Fig. 5.7. This schedule does not include any contingency for schedule delays caused by site selection difficulties, redesign, construction delays, transportation delays, or a delay in the approval of line item funding.

The critical path through the development of the domestic MOX fuel fabrication facility is through the conceptual design and the NRC licensing process before construction may begin. If either of these tasks delays in its schedule, the remainder of the implementation process will also be delayed. This critical path is shown in Fig. 5.7.

5.3.7 MOX Fuel Fabrication Facility Cost Summary

All of the OPCs are for the domestic fuel fabrication facility, as are most of the TEC "Other Life Cycle Costs." Table 5.6 shows the MOX fuel fabrication life cycle costs in the 24-category format. The lag storage part of the TEC, category 22, and most of category 23 cover the cost of MOX fuel fabrication in Europe for the Quick Start portions of the variant. European fuel fabrication adds $125M in MOX-related LCCs above those associated with the base case. MOX fuel–related costs before revenues total $1.5B. The government's net LCC after revenues from fuel sales is $146M.

5.3.8 MOX Fuel Fabrication Facility S&S Summary

The inherent risks associated with the domestic MOX fuel fabrication facility should not be significantly different than for the base case. It is assumed that all PuO_2 and MOX fuel will be transported in fully safeguarded ocean transport vessels. The design and level of protection that exist at European commercial facilities is quite varied, and a detailed S&S assessment would be needed. All of these facilities are subject to safeguards inspections by EURATOM. Some of the newer facilities use a high level of automation and thus may have a lower risk than has been described for the base case.

Table 5.10. MOX fuel fabrication activities schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Fuel Qualification Demonstration	60	4/1996	4/2001
European Facility Interactions	80	12/1998	8/2005
Domestic MOX Fuel Fabrication Facility	252	12/1996	12/2017
Site and Facility Selection	12	12/1997	12/1998
Select M&O Contractor	12	12/1998	12/1999
Licensing and Permitting	60	12/1997	12/2002
Design Process	60	12/1996	11/2001
Facility Modification	36	12/2001	12/2004
Preoperational Phase	24	12/2004	12/2006
Operation	108	12/2006	12/2015
D&D	24	12/2015	12/2017

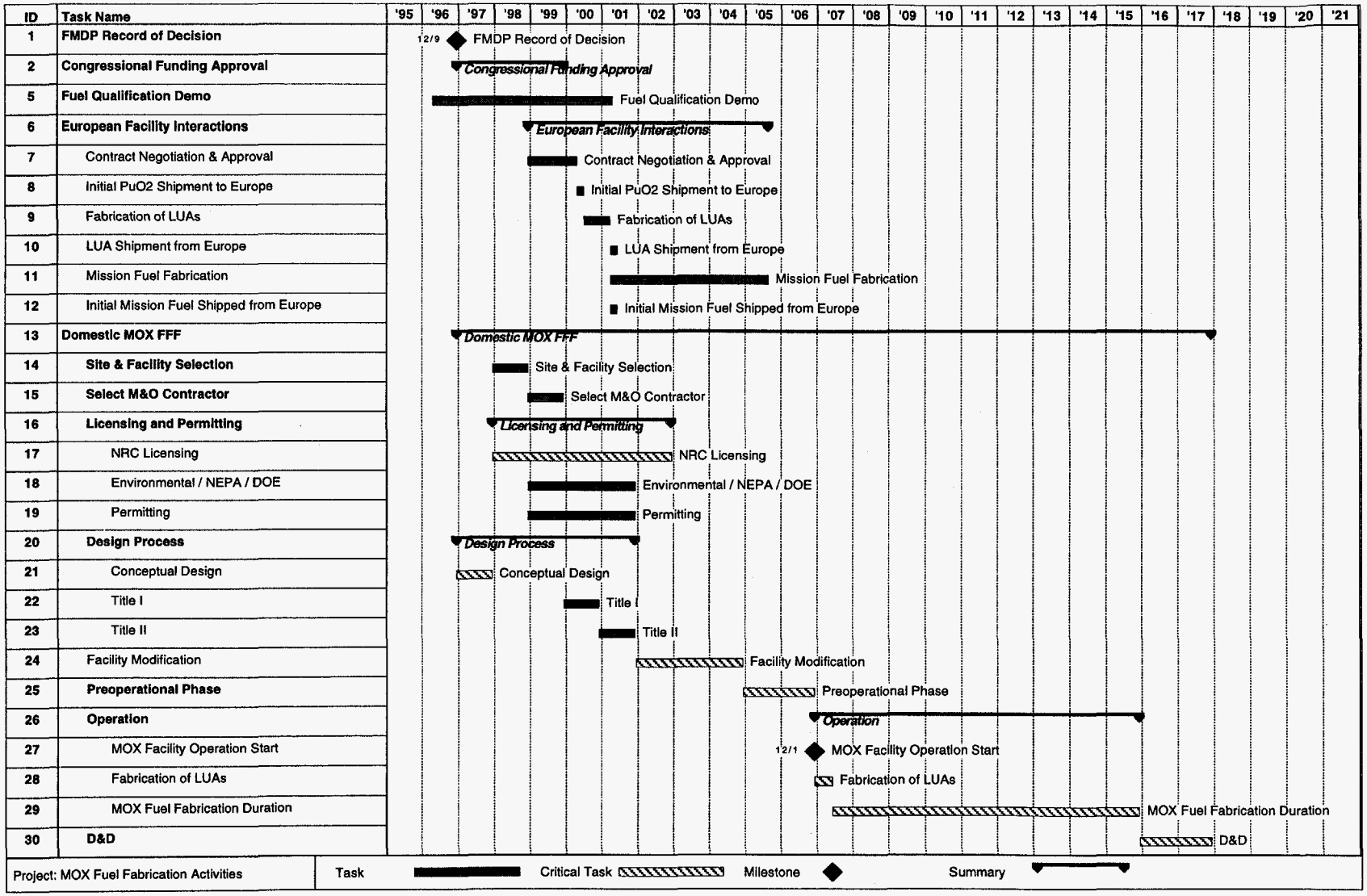


Figure 5.7. MOX fuel fabrication activities schedule summary

5.4 Quick Start Reactor Facility

5.4.1 Quick Start Reactor Facility Description

The existing LWR facility for this variant is identical to the base case discussed in Chap. 2.

5.4.2 Quick Start Reactor Modification

The existing LWR facility modification schedule and costs for this alternative are the same as described in Chap. 2.

5.4.3 Quick Start Reactor Licensing and Permitting

The Quick Start reactor licensing and permitting approach is essentially the same as that for the base-case LWR alternative, with the exception that two distinct LUA campaigns are conducted—one for the European fuel and one for the domestic fuel. The fuel qualification process begins 4.5 years earlier than in the base case because the European-fabricated LUAs are available much sooner than the domestically fabricated LUAs. This change in the fuel qualification and reload permit schedule is shown in Table 5.11 and as a part of Sect. 5.4.5.

This facility OPC is identical to the base-case LWR alternative (Table 5.12).

5.4.4 Quick Start Reactor Facility Operations

5.4.4.1 Quick Start Shipment and Storage

Approximately 2756 LWR MOX fuel assemblies will be fabricated from the 50 MT of PuO_2. For the Quick Start phase, approximately 375 assemblies (25 assemblies per reactor for 3 cycles) will be fabricated in Europe and shipped to the United States in the same ships used in the prior shipments of the PuO_2 packages. Each cargo ship will transport approximately 36 MOX fuel assembly packages.

Following the Quick Start phase, the domestic MOX fuel fabrication facility will produce the remaining fuel assemblies for the disposition mission (~2381). These MOX fuel assemblies will be shipped from the MOX fuel fabrication facility to the five existing LWR facilities. The MOX fuel fabrication facility is assumed to have the capacity to store completed fuel assemblies until they are needed. In addition, each reactor provides sufficient storage capacity for one reload.

Shipment Information—Table 5.13 provides an estimate of the number of shipments for the oceangoing portions of the shipment legs required to transport the fresh MOX fuel from the fuel fabrication facility to the existing LWR facility.

The same number of SST shipments (904) of fresh MOX fuel will be required for the Quick Start variant as will be required for the base-case LWR alternative (Chap. 2, Sect. 2.4.4.1).

Table 5.11. Existing LWR facility license and permit schedule

Task name	Duration (months)	Start	Finish
NRC Interactions	51	12/1999	2/2004
Environmental/NEPA/NRC	24	12/1999	11/2001
LUA and Reload Licenses	72	12/1999	11/2005
LUA Licensing	36	12/1999	11/2002
Reload Approval	18	5/2004	11/2005
Fuel Qualification—LUAs	126	6/2001	12/2011
European LUAs Arrive			6/2001
European LUA Irradiation	54	12/2002	6/2007
American LUAs Arrive			6/2007
American LUA Irradiation	54	6/2007	12/2011

Table 5.12. Reactor-related LCCs in 24-category format

Category	Cost category description	Five existing reactors	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Fee and transportation costs are based on 13.1 years; staffing costs are based on 17.6 years		
	Preoperational or OPC		
	Up-front costs:		
1	R&D	36	
2	NEPA, licensing, permitting	103	
3	Conceptual design	1	
4	QA, site qualification, S&S plans	2	
5	Postconstruction startup	22	
6	Risk contingency	0	
	TOTAL OPC	$164	
	Capital or TEC part of up-front cost:		
7	Title I, II, III engineering, design, and inspection	10	
8a	Capital equipment	0	
8b	Direct and indirect construction/modification	58	
9	Construction management	0	
10	Initial spares	0	
11	AFI	0	
12	Risk contingency	0	
	TOTAL TEC	$68	
	TOTAL UP-FRONT COST (TPC)	$232	
	Other LCCs:		
13	Operations and maintenance staffing (incremental) (17.6 years)	123	7.0
14	Consumables including utilities	0	0
15	Major capital replacements or upgrades	0	0
16	Waste handling and disposal	0	0
17	Oversight	0	0
18	M&O contractor fees		
19	Payments-in-lieu-of-taxes to local communities		
	TOTAL ANNUAL RECURRING COSTS	123	7.0
20	D&D (percentage of capital or dollar estimate)	0	
21	Revenues (if applicable) from sale of MOX or electricity	0	
22	Fees to privately owned facility (13.1 years)	515	39.3
23	Transportation of plutonium forms to facility (13.1 years)	26	2.0
24	Storage of plutonium at existing 94-1 site facility	N/A	
	TOTAL OTHER LCC	$664	$48.3[a]
	GRAND TOTAL ALL LCC (1996 $M)	$896	

[a]This annual cost would apply for the first 13.1 years.

Table 5.13. Parameters for fresh MOX fuel transport leg (ocean shipments)

Maximum material/package	Quantity plutonium/campaign (MT)	Estimated number of packages to be shipped	Number of ocean shipments/campaign
Two PWR assemblies	6.8	188	6—assuming 36 packages per ship

5.4.4.2 Quick Start Operations Process

The existing LWR facility for this variant is identical to the base case discussed in Sect. 2.4.4.2.

5.4.4.3 Reactor Facility Operations Schedule

The LUAs are loaded into the first unit as soon as the LUA license is granted and during a normal refueling period for the reactor. After the completion of the LUA review during the second irradiation cycle, the first European-fabricated mission fuel is loaded at the next scheduled refueling period in November 2005. The MOX fuel load and discharge schedule for the five reactors is shown in Table 5.14. After the spent fuel assemblies are discharged from the reactors, they are stored in the spent fuel storage pool for 10 years before being shipped to the HLW repository facility. The existing LWR facilities operational schedule is shown in Table 5.15 and as a part of Sect. 5.4.5.

5.4.4.4 Quick Start Reactor Facility Operations Cost

The annual incremental operations costs (Table 5.12) for the five PWRs are the same as for the base case. Because of the longer reactor loading schedule associated with European-fabricated fuel, the reactor campaign will accrue incremental operations costs for 17.6 years instead of 14.3 years for the base case. The fee is based on 13.1 years of reactor operations (first MOX bundles into the reactor until the last MOX bundle is put into the reactor) rather than 9.8 years as in the base case. The extension of the irradiation campaign that results from the Quick Start variant adds $105M in reactor-related LCCs to the base case.

5.4.5 Quick Start Reactor Facility Schedule Summary

The overall reactor facility implementation schedule is summarized in Table 5.16 and shown in Fig. 5.8. The critical path for this facility is the intermediate approval of line item funding, utility selection, and completion of the LUA license and is shown in Fig. 5.8.

5.4.6 Quick Start Reactor Facility Cost Summary

Table 5.12 shows the reactor-related LCCs in the 24-category format. The total LCC is less than $0.9B, including the incentive fee.

5.4.7 Quick Start Facility S&S Summary

The Quick Start variant S&S issues for the reactor facilities are the same as those for the base-case option discussed in Chap. 2.

5.4.8 Quick Start Reactor Facility Technical Viability Summary

The technical viability issues for the Quick Start variant are identical to those of the base-case alternative described in Chap. 2, Sect. 2.4.9.

5.5 HLW Repository

The HLW repository is identical to that of the base-case alternative (Chap. 2).

The HLW repository facility schedule for this alternative is the same as described in Chap. 2 except for the spent MOX fuel delivery schedule. The first spent fuel will arrive at the HLW repository facility in June 2020, and the last delivery is scheduled in August 2033.

The HLW repository cost to the utility is assumed to be 1 mill/kWh of power generated. No incremental cost to the government is assumed.

Table 5.14. MOX fuel charging/discharging schedule employing five Westinghouse PWRs without IFBA (Quick Start scenario)

Time from MOX load in first reactor (years)	Assemblies loaded in reactor						Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	5	Cumulative			
0.0	25					25	0.5	10.6	
0.4		25				50	0.9	21.1	
0.8			25			75	1.4	31.7	
1.1				25	25	125	2.3	52.8	
1.5	25					150	2.7	63.3	
1.9		25				175	3.2	73.9	
2.3			25			200	3.6	84.4	
2.6				25	25	250	4.5	105.5	
3.0	25					275	5.0	116.1	
3.4		25				300	5.4	126.6	
3.8			25			325	5.9	137.2	
4.1				25	25	375	6.8	158.3	
4.5	84					459	8.3	193.7	25
4.9		84				543	9.9	229.1	50
5.3			84			627	11.4	264.6	75
5.6				84	84	795	14.4	335.5	125
6.0	84					879	16.0	370.9	150
6.4		84				963	17.5	406.4	175
6.8			84			1047	19.0	441.8	200
7.1				84	84	1215	22.0	512.7	250
7.5	84					1299	23.6	548.2	275
7.9		84				1383	25.1	583.6	300
8.3			84			1467	26.6	619.1	325
8.6				84	84	1635	29.7	690.0	375
9.0	84					1719	31.2	725.4	459
9.4		84				1803	32.7	760.9	543
9.8			84			1887	34.2	796.3	627
10.1				84	84	2055	37.3	867.2	795
10.5	84					2139	38.8	902.7	879
10.9		84				2223	40.3	938.1	963
11.3			84			2307	41.9	973.6	1047
11.6				84	84	2475	44.9	1044.5	1215
12.0	84					2559	46.4	1079.9	1299
12.4		84				2643	48.0	1115.3	1383
12.8			84			2727	49.5	1150.8	1467
13.1				29		2756	50.0	1163.0	1635
13.5									1719
13.9									1803

Table 5.14. MOX fuel charging/discharging schedule employing five Westinghouse PWRs without IFBA (Quick Start scenario) (cont.)

Time from MOX load in first reactor (years)	Assemblies loaded in reactor						Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	4	5	Cumulative			
14.3									1887
14.6									2055
15.0									2139
15.4									2223
15.8									2307
16.1									2475
16.5									2559
16.9									2643
17.3									2727
17.6									2756

Notes:

1. Plutonium enrichment = 4.3%.
2. Plutonium per assembly = 18.15 kg.
3. HM per assembly = 421.4 kg.
4. Assemblies per core = 193.
5. Reload batch size = 25 per reactor for three cycles, then 84 per reactor.
6. Plutonium dispositioned per year = 1.7 MT/year (average) for three cycles, then 4.95 MT/year (average).
7. HM throughput per year = 39.5 MT/year (average) for three cycles, then 119.3 MT/year (average).
   HM throughput used for sizing MOX plant = 118 based on equilibrium cycle.
8. Cycle times including allowance for 80% capacity factor:
   Refueling cycle time = 1.5 years.
   Fuel in-core residence time = 4.5 years.
9. Average discharge exposure = 45,000 MWd/MT.
10. At 13.1 years, reactors transition to LEU fuel.

5.6 Quick Start Variant Summary

5.6.1 Quick Start Schedule Summary

The Quick Start variant schedule is a combination of the individual facility schedules previously discussed. This overall schedule is summarized in Table 5.17 and shown in Fig. 5.8. The plutonium disposition mission begins when the first mission fuel is loaded into a reactor in November 2005 and is complete after the last core load, which contains MOX fuel assemblies, has been irradiated for a single cycle in July 2020. The overall mission time is 14.6 years and starts 9 years after ROD. Thus, the irradiation campaign begins approximately 4.5 years sooner and ends 15 months before the base-case start and end dates.

5.6.2 Quick Start Cost Summary

The Quick Start variant allows the MOX irradiation mission to be moved forward by several years at an additional cost above the base case of $205M. This variant still requires the United States to construct a MOX plant; however, a significant amount of MOX fuel can be produced in Europe while the domestic MOX plant is under construction.

Given the assumed EuroMOX fuel price of $1500/kgHM, the cost of European fabrication is $237M. The investment cost for this variant also includes $10M for a MOX storage facility at a secure East Coast port to handle the fuel bundle shipments from Europe. Staffing for the Quick Start option is expected to be close to that in the base-case alternative (Table 2.42). Staff at European facilities are not counted.

Table 5.15. Existing LWR facility operations schedule

Task name	Duration (months)	Start	Finish
Reactor "Ready" to Accept MOX			2/2004
Fuel Qualification—LUAs	126	6/2001	12/2011
European LUAs Arrive			6/2001
European LUA Irradiation	54	12/2002	6/2007
American LUAs Arrive			6/2007
American LUA Irradiation	54	6/2007	12/2011
Reactor Facility(-ies) Operation	211	11/2005	7/2023
Unit 1			
EuroMOX Loading Duration	54	11/2005	5/2010
American MOX Loading Duration	90	5/2010	11/2017
Unit 2			
EuroMOX Loading Duration	54	4/2006	10/2010
American MOX Loading Duration	90	10/2010	4/2018
Unit 3			
EuroMOX Loading Duration	54	8/2006	2/2011
American MOX Loading Duration	90	2/2011	8/2018
Unit 4			
EuroMOX Loading Duration	54	1/2007	7/2011
American MOX Loading Duration	90	7/2011	1/2019
Unit 5			
EuroMOX Loading Duration	54	1/2007	7/2011
American MOX Loading Duration	72	7/2011	7/2017
Last Assemblies—Single Cycle	18	1/2019	7/2020
Last Assembly Discharged	54	1/2019	7/2023
Spent Fuel Storage	277	5/2010	7/2033
First MOX in Spent Fuel Pool	120	5/2010	5/2020
Last MOX	120	7/2023	7/2033

Table 5.16. Existing LWR facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval	36	12/1996	12/1999
Utility Selection	12	12/1998	12/1999
Licensing	51	12/1999	2/2004
Reactor Modifications	48	12/1999	11/2003
LUA and Reload Licenses	72	12/1999	11/2005
LUA Licensing	36	12/1999	11/2002
Reload Approval	18	5/2004	11/2005
Fuel Qualification	126	6/2004	12/2011
European LUA Arrives			6/2001
European LUA Irradiation	54	12/2002	6/2007
American LUA Arrives			6/2007
American LUA Irradiation	54	6/2007	12/2011
Reactor Facility (-ies) Operation	211	11/2005	7/2023
EuroMOX Loading Duration (Units 1–5)	54	11/2005	5/2010
American MOX Loading Duration (Units 1–5)	103	5/2010	1/2019
Last Assemblies—Single Irradiation Cycle	18	1/2019	7/.2020
Last Assembly Discharged After Three Full Cycles	54	1/2019	7/2023
Spent Fuel Storage	277	5/2010	7/2033
First MOX in Spent Fuel Pool	120	5/2010	5/2020
Last MOX	120	7/2023	7/2033

Figure 5.9 compares the LCCs for all facilities, and Table 5.18 shows LCCs in the 24-category format. The LCCs for all facilities combined are shown in Fig. 5.10. Figure 5.11 shows the annual constant dollar cost to the U.S. government for this variant. If the net cash flows are discounted at a 5% real discount rate, a total discounted life cycle cost (TDLCC) of $1.44B results.

The cost section (Chap. 4) of the TSR did not discuss the Quick Start option. If the TSR assumption of no incentive fee were assumed, the $2429M LCC would be reduced to $1914M, as shown at the bottom of Table 5.18. Section H-5 of Appendix H provides data on the Quick Start variant using the TSR cost bases (no fee).

5.6.3 Quick Start S&S Summary

There are three major differences between this variant and the base-case LWR alternative. First, the initial fuel fabrication will be done in Europe. Second, the lag storage facility is located on a military installation that will be used to stage the fresh MOX fuel from Europe. Finally, there is transatlantic transport of the material for the fuel rods and fresh MOX fuel. The exact locations and procedures for the change of custody of the nuclear material for these three facility/transport activities have not been determined at this time. If the material is staged on a U.S. military installation (e.g., naval base), then the installation safeguards requirements would be applicable. It is likely that either DOE's or NRC's guidelines will apply. For the fuel fabrication facility, both national and EURATOM guidelines will apply. During transport of the material on foreign flagged ships, safeguards requirements would follow that nation's guidelines. In addition, specific physical protection guidelines have been developed for the transport of nuclear material by both the IAEA and other agencies, and these may also apply.

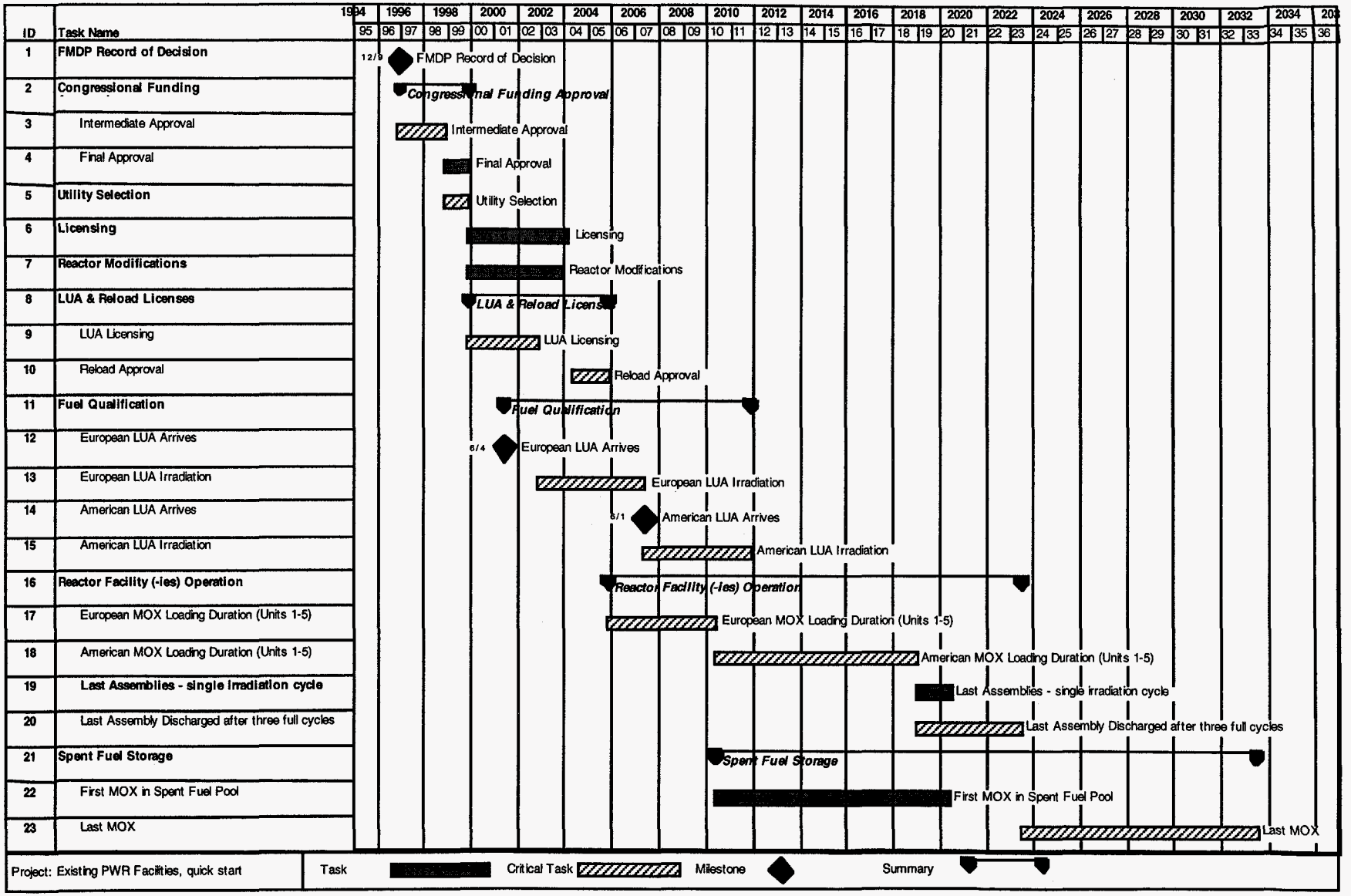


Figure 5.8. Existing LWR facility schedule summary

Table 5.17. Existing LWR Quick Start alternative schedule summary

Task name	Duration (years)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval Process	3	12/1996	12/1999
PuP Facility and Prototype	21.9	10/1995	9/2017
R&D and Facility Design	6.3	10/1995	1/2002
Prototype Operation	6	1/1998	1/2004
Licensing, Permitting, and Siting	5	12/1996	12/2001
Facility Modification and Preoperation	4.5	1/2002	7/2006
Production Facility Operation	9.1	7/2006	8/2015
D&D	2	9/2015	9/2017
EuroMOX Fuel Fabrication Facility	6.8	12/1998	8/2005
Contract Negotiation	1.4	12/1998	4/2000
Fabricate and Ship LUAs	1.1	4/2000	6/2001
Mission Fuel Fabrication	4.5	3/2001	8/2005
Domestic MOX Fuel Fabrication Facility	21.6	4/1996	12/2017
Fuel Qualification	5	4/1996	4/2001
Licensing, Permitting, and Siting	5	12/1997	12/2002
Facility Design, Modification, and Preoperation	10	12/1996	12/2006
Fabrication of LUAs	0.5	12/2006	6/2007
Operation	8.5	6/2007	12/2015
D&D	2	12/2015	12/2017
Reactors	34.6	12/1998	7/2033
Utility Selection	1	12/1998	12/1999
LUA Licensing	3	12/1999	11/2002
European LUAs	4.5	12/2002	6/2007
American LUAs	4.5	6/2007	12/2011
MOX Loading Duration	13.1	11/2005	1/2019
Spent Fuel Pool	23.1	5/2010	7/2033
Repository			
Licensing and Construction	8.5	3/2002	8/2010
MOX Delivery	13.1	6/2020	8/2033

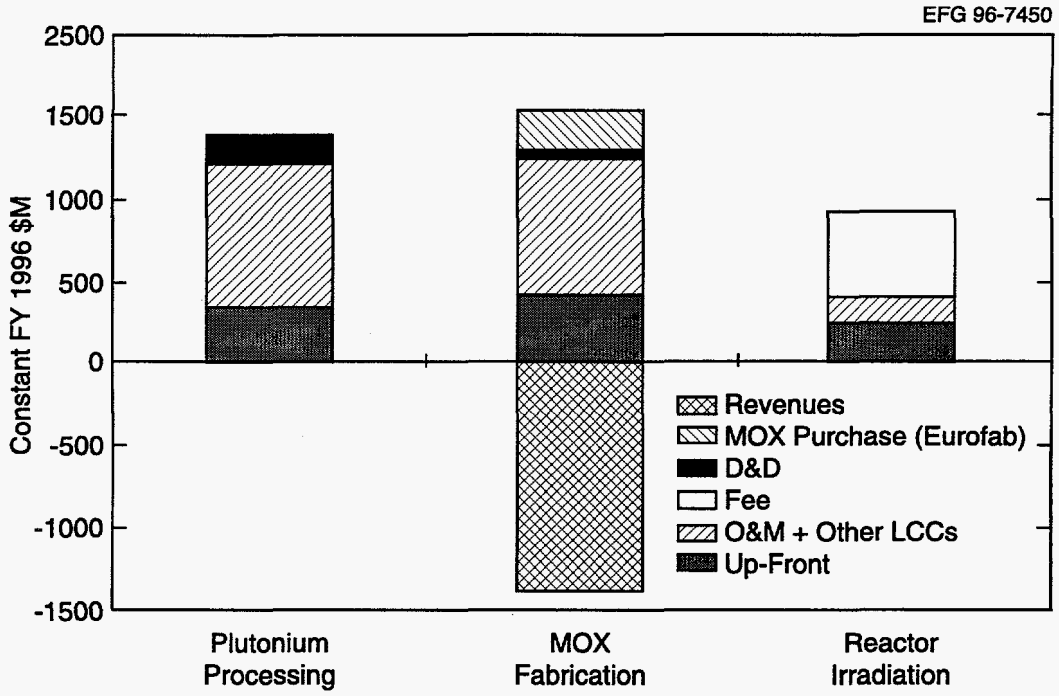


Figure 5.9. LCCs and revenues by facility

Applicable IAEA safeguards requirements would exist for the European fuel fabrication facility and the transport of the nuclear material. Unless classified restricted material is also present at the lag storage facility, it is assumed that IAEA safeguards measures would apply. There are still a number of unknowns at this time relating to how IAEA safeguards would be applied at the lag storage, sea transport, and materials transfer points, but there is no reason to believe that implementation of appropriate safeguards would pose a significant problem.

The lag storage facility is the one new facility that is not required by the base case. It must meet the requirements for storage of Category I SNM. The FMDP material at this facility would consist of outbound PuO_2 in containers (possibly inside SSTs) and inbound fresh fuel assemblies from Europe.

Item accountancy would be used for material received and handled in the facility, and many of the operations would be performed using robotic or special handling equipment. Only NDA measurements would likely be performed and perhaps only confirmatory measurements done at this facility.

The primary S&S transport concerns for this alternative are the loading and unloading of the ships and the transport of the material on these ships. Such activities are not new to the European commercial MOX fuel fabrication facilities, and necessary physical protection and accountability measures should be in place. IAEA safeguards would be implemented for these activities.

5.6.4 Quick Start Technical Viability Summary

Technical viability issues for the Quick Start option are identical to those of the existing LWR base-case alternative (Sect. 2.6.4), except as noted in Appendix E.

5.6.5 Quick Start Transportation Summary

Multiple facilities are required for disposition of approximately 50 MT of excess weapons-usable plutonium as MOX fuel in an existing LWR. The plutonium moves sequentially between each facility from its present locations (storage vaults at a number of DOE facilities) through the various processing, fabrication, and reactor facilities, and ultimately, to emplacement as spent fuel at an HLW repository. Under the Quick Start variant, it is assumed that the initial partial core load of MOX fuel for the LWRs is produced in Europe (roughly three cycles), followed by completion of MOX fuel fabrication in the United States.

Table 5.18. Summary of LCCs for all Quick Start facilities in 24-category format[a]

Category	Cost category description	LANL preproduction + PuP at SRS		Eurofab + U.S. MOX plant		Five existing reactors		Repository		Lump sum total for all facilities ($M)
		Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	
	Years of operation =	8.5 at SRS 6+ at LANL		8.5 in U.S. 4.1 in Europe		13.1 (for fee and transportation);				
	Preoperational or OPC					17.6 (for incremental staffing)				
	Up-front costs									
1	R&D (SRS portion for PuP)	40		21		36				97
2	NEPA, licensing, permitting	6		35		103				144
3	Conceptual design	3		2		1				6
4	QA, site qualification, S&S plans	0		1		2				3
5	Postconstruction startup	50		41		22				113
6	Risk contingency	11		0		0				11
	TOTAL OPC	$110		$100		$164		0		374
	"Capital" or "TEC" up-front costs									
7	Title I, II, III engineering, design, and inspection	17		48		10				75
8a	Capital equipment	34		150		0				184
8b	Direct and indirect construction/modification	32		51		58				141
9	Construction management	4		0		0				4
10	Initial spares	3		12		0				15
11	AFI	25		39		0				64
12	Risk contingency	56		0		0				56
	TOTAL TEC	$171		$300		$68		0		539
	SUBTOTAL UP-FRONT COST (TPC)	$281		$400		$232		0		913

Table 5.18. Summary of LCCs for all Quick Start facilities in 24-category format[a] (cont.)

Category	Cost category description	LANL preproduction + PuP at SRS		Eurofab + U.S. MOX plant		Five existing reactors		Repository		Lump sum total for all facilities ($M)
		Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	Lump sum ($M)	Annual ($M/year)	
L-1	Plutonium processing at LANL (ARIES demonstration and prototype) and MOX lag storage facility	$57		$10		0				67
	Total up-front costs (TPC)	$338		$410		$232		0		980
	Other LCC:									
13	Operations and maintenance staffing	595	70.0	282	33.1	123	7.0			1000
14	Consumables including utilities	72	8.5	279	32.8	0	0			351
15	Major capital replacements or upgrades	0	0	147	17.3	0	0			147
16	Waste handling and disposal	56	6.6	59	6.9	0	0			115
17	Oversight	9	1.0	9	1.0	0	0			18
18	M&O contractor fees	15	1.7	16	1.8	0	0			31
19	Payments-in-lieu-of-taxes to local communities	7	0.9	8	0.9	0	0			15
20	D&D	169		60		0				229
21	Revenues (if applicable) MOX or electricity	0		–1387	–110.1[b]	0				–1387
22	Government fees to private-owned facility (utility or Eurofabber)	0		237	57.8	515	39.3			752
23	Transportation of plutonium forms to facility	35	2.4	26	2.1[b]	26	2.0			87
24	Storage of plutonium at existing 94-1 site facility	N/A								0
L-2	PuP at LANL (halides, ARIES prototype)	91	15.2	0	0	0	0			91
	TOTAL OTHER LCC	$1049	$106.3	–$264	$82.3[b,c]	$664	$48.3[d]	0		$1449
	GRAND TOTAL LCC	$1387		$146		$896		0		$2429
	GRAND TOTAL LCC WITHOUT INCENTIVE FEE[e]	$1387		$146		$381		0		$1914

[a] All costs in constant 1996 $M.

[b] Annual costs based on 12.6 years (8.5 for U.S. MOX, 4.1 for EuroMOX).

[c] Weighted average annual cost for MOX ($96.8M/year for U.S. MOX, $57.8M/year for Eurofab; transportation and revenues not included).

[d] This annual cost would apply during the first 13.1 years only.

[e] The incentive fee was not applied in the TSR estimates.

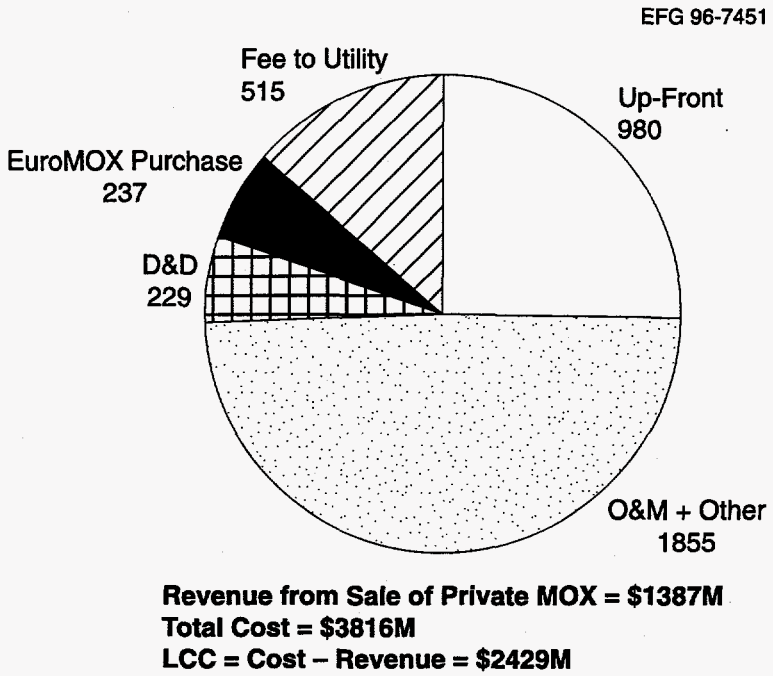


Figure 5.10. LCCs by major cost category (after MOX sales revenues)

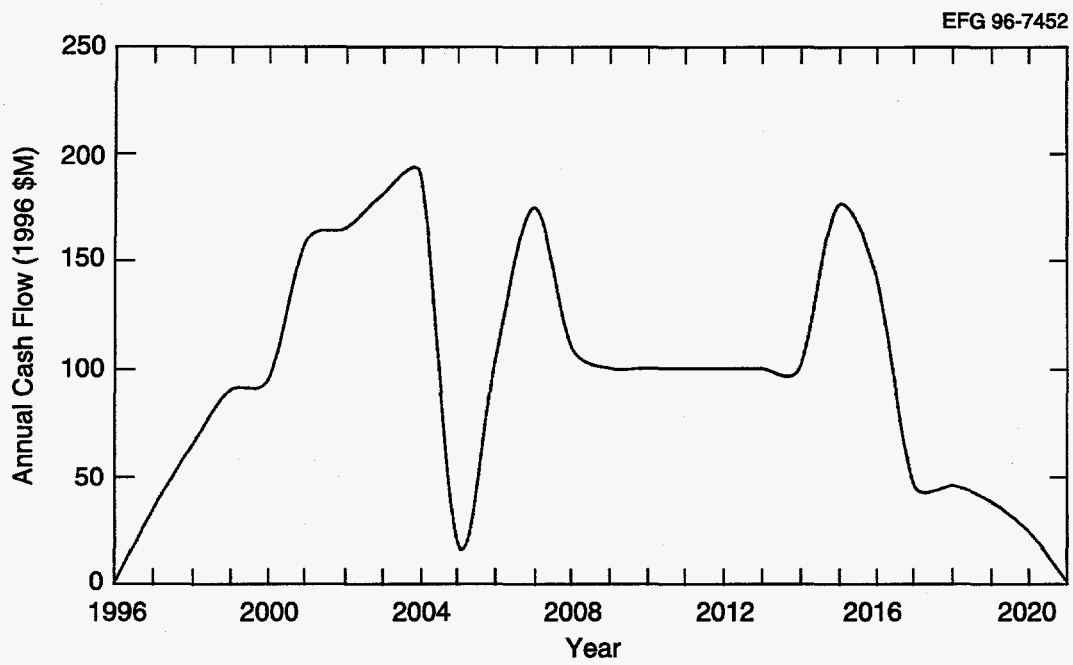


Figure 5.11. Annual constant dollar net cash flow from the U.S. government (after MOX sales revenues)

Figure 5.2 provides a simplified flowchart of the transportation segments associated with the existing LWR Quick Start disposition variant. Actual plutonium processing and fabrication facility locations will be determined by DOE following the ROD. For analysis, it has been assumed that the excess plutonium is in interim storage at many locations within the DOE weapons complex. This material is first packaged and transported to a PuP facility [assumed for analysis purposes to be located at the Savannah River Site (SRS)], where the material is converted to PuO_2. The PuO_2 is then repackaged and transported by SST to a U.S. coastal port for transport by special cargo ship to Europe (assumed for analysis purposes to be either BNFL's, COGEMA's, or Belgonucleaire's MOX fuel fabrication facility). Once fabricated, the fresh MOX fuel is packaged and returned to the U.S. coastal port for transport by SST to the five existing LWRs. Following completion of the U.S. MOX fuel fabrication facility, the facility interfaces for the remainder of the disposition mission result in domestic-only transport legs, as shown in Fig. 5.3.

Spent fuel discharged from each reactor is first stored in spent fuel pools at each reactor for 10 years. Ultimately, the spent fuel is packaged and transported to an HLW repository for emplacement in a geologic repository.

6. Existing LWR Alternative: Hybrid Variant

6.1 Introduction

All of the plutonium disposition approaches currently under consideration in the FMDP involve inherent cost and schedule uncertainty caused by a variety of political, institutional, and technical factors. One approach to minimizing the overall risk of delaying the plutonium disposition mission is to employ multiple disposition technologies (such as reactor-based and immobilization-based disposition). This approach avoids many of the risks inherent in the use of a single disposition technology. This chapter presents a preliminary analysis of a hybrid case in which three existing LWRs are employed to disposition 32.5 MT of plutonium, and the remaining 17.5 MT of plutonium is dispositioned via either immobilization or borehole technologies. No discussion of the immobilization or borehole technologies is included here, but these technologies are discussed in separate reports prepared by the FMDP Immobilization and Borehole Alternative Teams.

Because of the preliminary nature of this analysis and the lack of a conceptual design for the hybrid PuP facility(is), no detailed discussion of the PuP facility and related issues is provided. For the purposes of this discussion and evaluation, it has simply been presumed that an ARIES-based plutonium production facility will provide 32.5 MT of PuO_2 for use in MOX fabrication over a 10-year operating period. The focus of this chapter is, then, to discuss the impact of the hybrid mission on MOX fabrication and reactor operations. The top-level flow diagrams for this variant is depicted in Fig. 6.1.

The power rating of the reactors chosen for the plutonium disposition mission, coupled with the reactor core design and burnup, establishes the plutonium

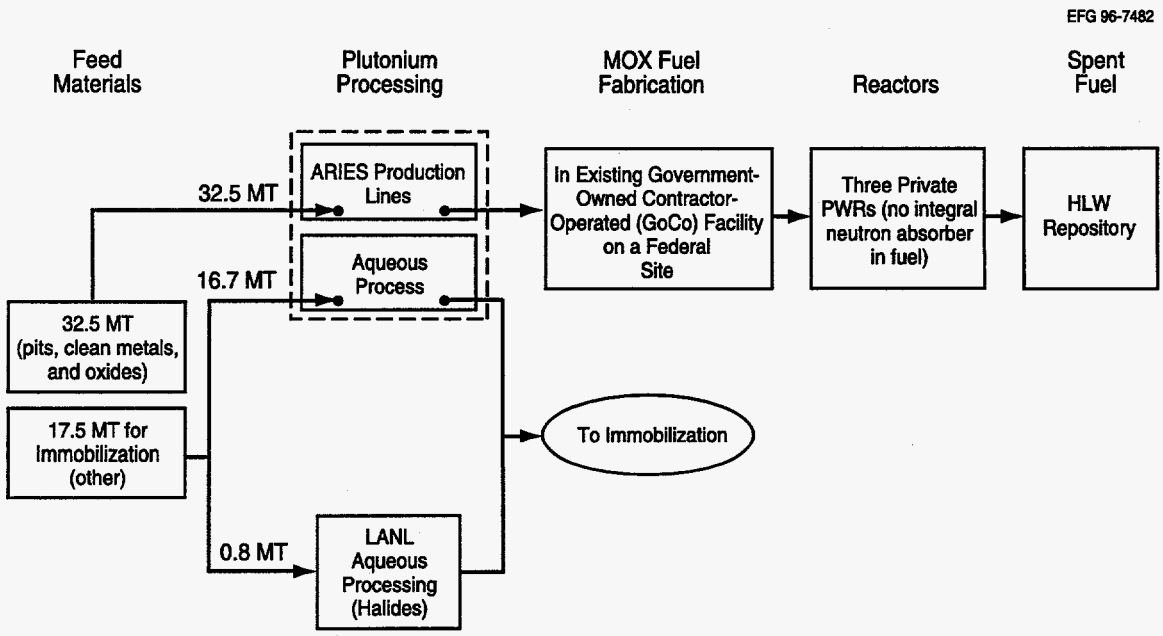


Figure 6.1. 50-MT plutonium disposition flow diagram for the hybrid variant

throughput for the reactors. This value, in turn, establishes the throughput for all prior operations to support fuel fabrication.

6.1.1 General Assumptions

The general assumptions for this case are identical to those discussed in Chap. 2 except that the inventory of surplus plutonium assumed to be processed via the reactor alternative is only 32.5 MT. The remaining 17.5 MT of plutonium is assumed to be processed by another disposition technology such as immobilization- or borehole-based disposition.

6.1.2 Summary Description of LWR Hybrid Variant Disposition Facilities

The facilities included in this hybrid variant are as follows:

PuP Facility. The proposed baseline PuP facility would be located in an existing federally owned site. The plutonium pits and clean metal (~32.5 MT of plutonium) would be processed by the ARIES HYDOX dry processing procedure, and the other feed material (~17.5 MT of plutonium) would be processed as required for feed to the immobilization or borehole facilities.

MOX Fuel Fabrication Facility. A federally owned MOX fuel fabrication facility located in an existing building on an existing federal site will receive the PuO_2, rod and bundle components, depleted UO_2, and additives for fabrication of MOX fuel; perform the assembly of fuel bundles; and ship the fuel to the utility. This facility will be NRC licensed.

LWRs. Three large LWRs will irradiate the MOX fuel sufficiently for it to meet the SFS upon discharge from the reactor. These reactors could be PWRs or BWRs. For this alternative, three 3411-MW(t) [1150-MW(e)] Westinghouse PWRs were chosen as surrogate reactors.

HLW Repository. The HLW repository will receive the spent fuel in large canisters, transfer the sealed canisters to disposal casks, and move the casks underground for final disposition. The HLW repository is included here for completeness. Emplacement in the geologic repository, however, is not required to achieve the SFS.

It is imperative that each facility provide acceptable material to the follow-on facility in a timely manner to meet the desired mission schedule. Plutonium oxide from the PuP facility is required to fabricate MOX fuel for use in the reactors. After cooling for 10 years in the spent fuel pool at the reactor facility, spent fuel is sent to the HLW repository. Figure 6.2 shows the proposed production schedule for the PuO_2 and MOX fuel, as well as the fuel loading schedule for the reactors.

Figure 6.3 shows the MOX fuel assembly processing schedule, fuel loading schedule, and the schedule for sending spent fuel to the repository.

6.1.3 Description of Facility Interfaces for the Hybrid Variant

The transportation aspects of this variant are identical to those described in the existing LWR alternative base case except that only 32.5 MT of plutonium is involved in reactor disposition. Figure 6.4 provides a simplified flowchart of the transportation segments of the variants. See Sect. 2.1.3 for additional information.

6.2 PuP Facility

The PuP facility functions for this variant are assumed to be based on the ARIES process. PuP for the non-reactor portion of the hybrid option will be a function of the technology selected for disposition and may be collocated with the disposition facility described in Chap. 2.

6.2.1 PuP Facility Schedule Summary

The overall PuP facility implementation schedule for the reactor feed material is assumed to be the same as described in Sect. 2.2. The PuP facility schedule summary is shown in Table 6.1 and Fig. 6.5. The reactor portion of the PuP costs cannot be estimated until additional technology and siting decisions are made.

6.3 MOX Fuel Fabrication Facility

The MOX fuel fabrication facility for this hybrid variant is similar in function to the MOX fuel fabrication facility described in Chap. 2. The MOX facility would be smaller (fewer reactors supplied with MOX fuel) and less expensive than the facility described in Chap. 2, because only 32.5 MT of plutonium will be

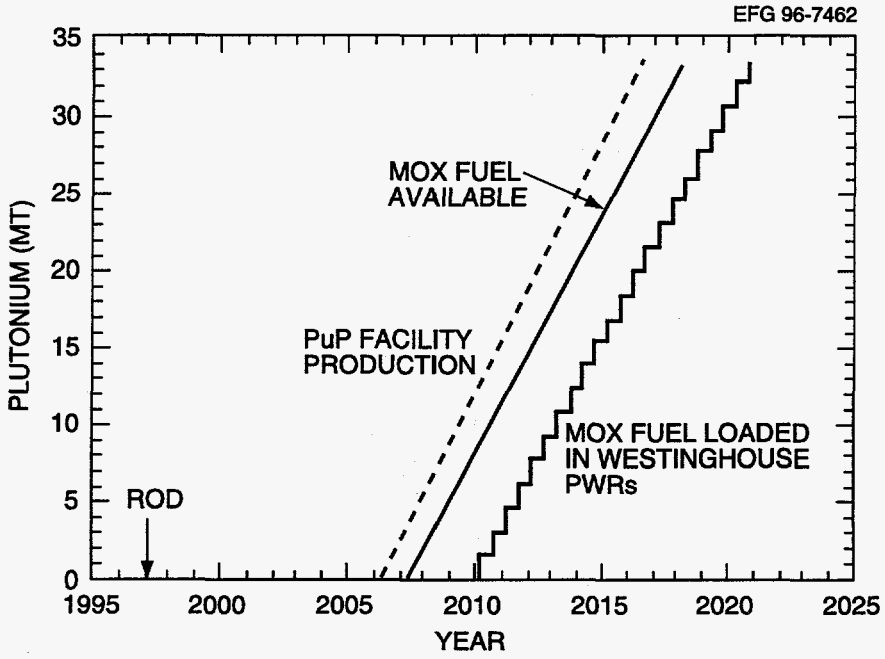


Figure 6.2. Plutonium disposition schedule for the hybrid variant

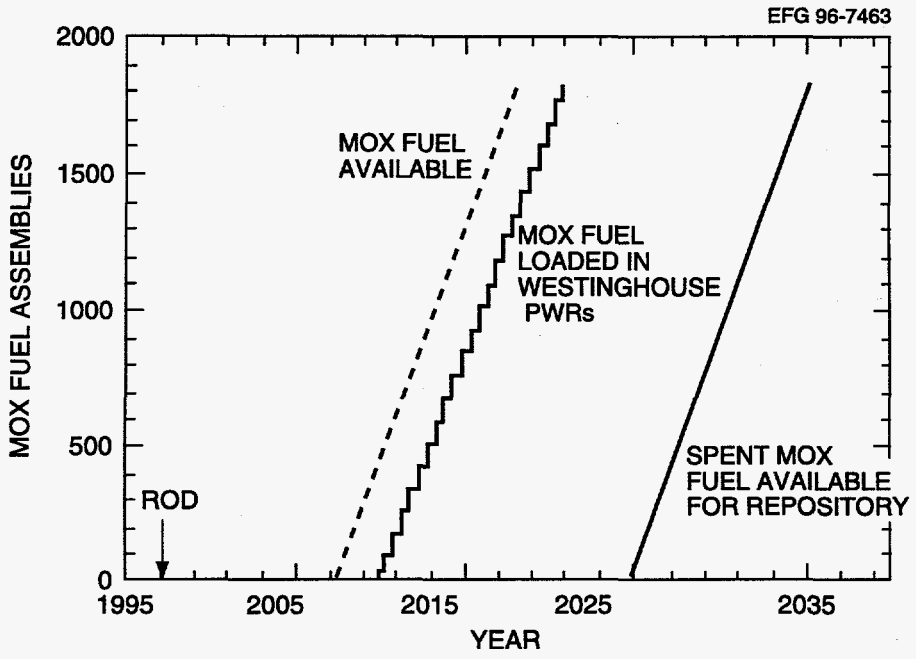


Figure 6.3. MOX fuel assembly processing schedule for the hybrid case

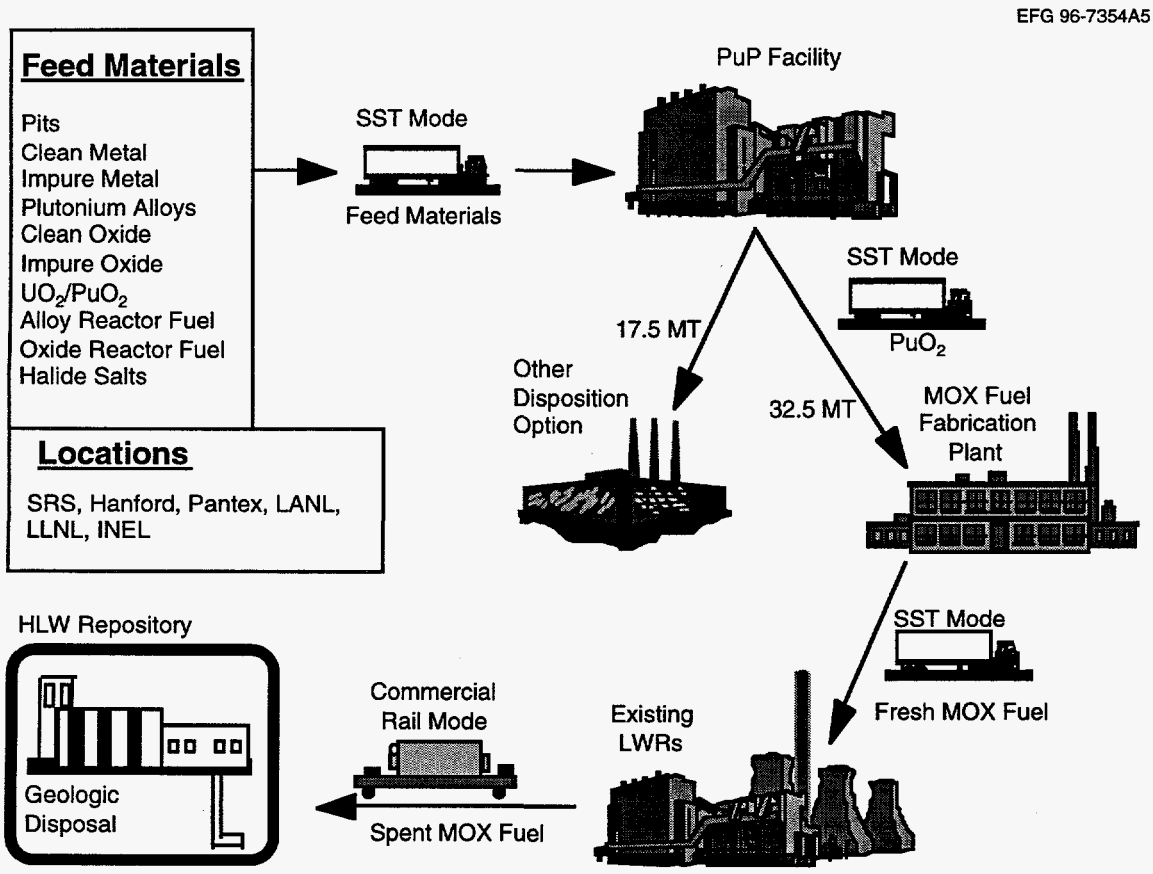


Fig. 6.4. Simplified flowchart showing transportation segments for the hybrid case existing LWR alternative

processed into MOX fuel in this variant. For a detailed description of the MOX facility, see Sect. 2.3.1.

Table 6.2 lists the batch characteristics for the receiving and shipping, fuel fabrication, and fuel bundle shipping process.

6.3.1 MOX Fuel Fabrication Facility Schedule Summary

The preoperational MOX fuel fabrication facility implementation schedule for this variant is the same as described in Sect. 2.3. The MOX fuel fabrication facility will begin operation in 2007. Six months later, the LUAs will be ready to load into the first reactor. Following this startup period, the MOX fuel fabrication facility will operate for 10.7 years with an annual plutonium throughput rate of 3.0 MT to supply fuel for the three existing PWRs at the specified loading rate. This throughput assumes an annual output of 170 assemblies for a total of 1819 assemblies. The MOX fuel fabrication facility schedule summary is shown in Sect. 6.6.1.

6.3.2 MOX Fuel Fabrication Facility Cost Summary

The MOX fuel fabrication facility for the hybrid variant is designed for a production rate of 71.7 MTHM/year and will operate for 10.7 years. This capacity is smaller than feed rates required for the base-case MOX fuel fabrication facility, which has a capacity of 118 MTHM/year to serve five PWRs. An anticipated LCC savings (before revenues from sale of MOX fuel at the LEU fuel equivalent price of $1193/kgHM) of $295M will be realized as a result of the smaller capacity for the hybrid MOX fuel fabrication plant as compared with the base-case plant. Because less MOX

Table 6.1. Existing LWR 32.5-MT variant schedule summary

Task name	Duration (years)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval Process	3	12/1996	12/1999
PuP Facility	22.8	10/1995	7/2018
RD&D	3	10/1995	10/1998
Oversight, Permitting & Siting	5	12/1996	12/2001
Design	5.1	12/1996	1/2002
Facility Modification & Preoperation	4.5	1/2002	7/2006
Operation	10	7/2006	7/2016
Decontamination & Decommissioning	2	8/2016	7/2018
MOX Fuel Fabrication Facility	23.8	4/1996	2/2020
Fuel Qualification	5	4/1996	4/2001
Licensing, Permitting & Siting	5	12/1997	12/2002
Design	5	12/1996	12/2001
Facility Modification & Preoperation	5	12/2001	12/2006
Fabrication of LUAs	0.5	12/2006	6/2007
Operation	10.7	6/2007	2/2018
Decontamination & Decommissioning	2	2/2018	2/2020
Reactor Facility(-ies)	36.5	12/1998	6/2035
Utility Selection	1	12/1998	12/1999
Licensing	4.2	12/1999	2/2004
Reactor Modifications	4	12/1999	11/2003
Reactor "Ready" to Accept MOX			2/2004
Lead Use Assemblies	4.5	6/2007	12/2011
MOX Loading Duration	10.5	5/2010	11/2020
Single Irradiation Cycle of Last MOX	1.5	11/2020	5/2022
Spent Fuel Pool Duration	20.5	12/2014	6/2035
HLW Repository Facility			
Licensing	8.5	3/2002	8/2010
Construction	5.5	3/2005	8/2010
Spent MOX Fuel Delivery	10.5	12/2024	6/2035

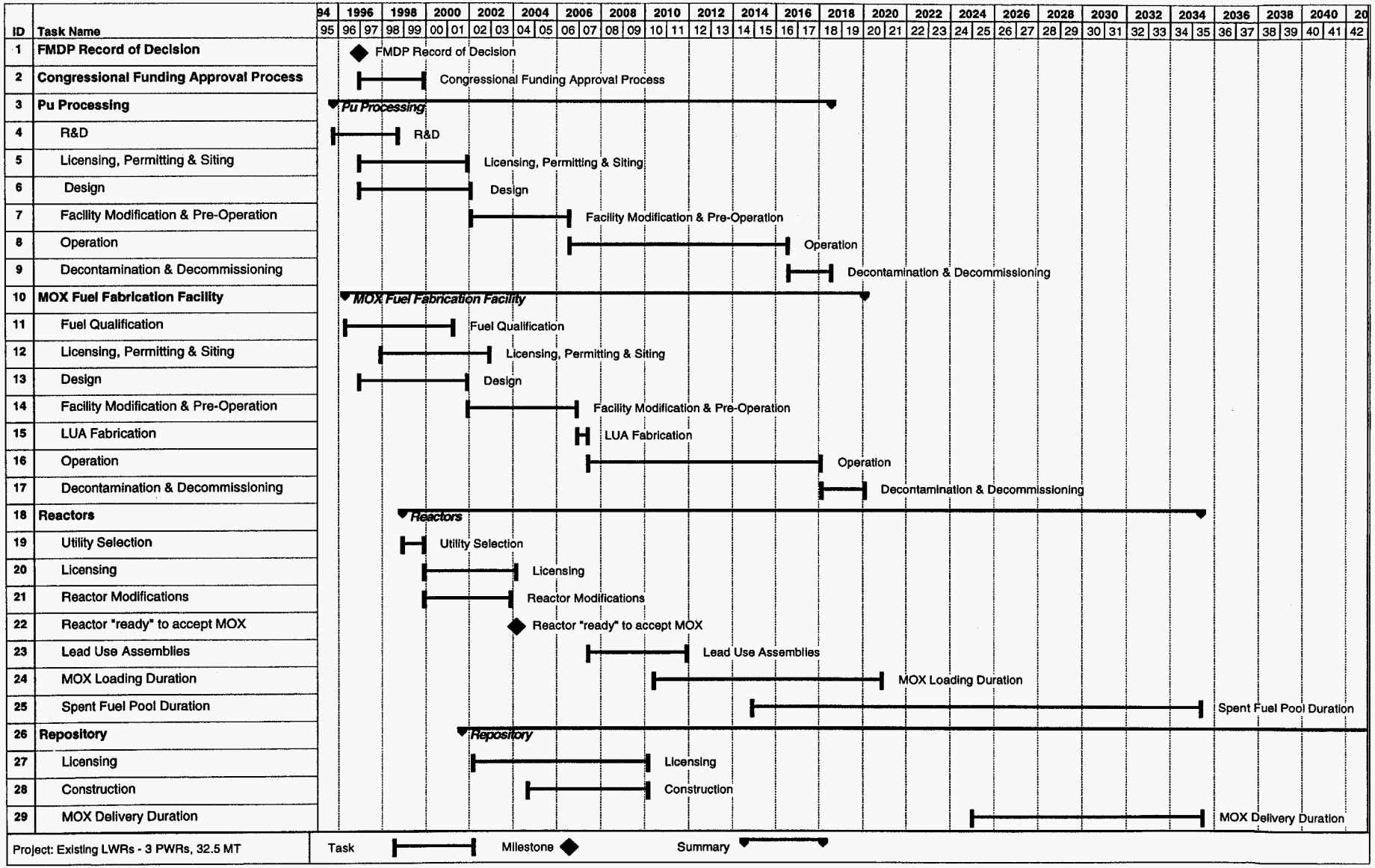


Figure 6.5. Existing LWR alternative 32.5-MT case schedule summary

Table 6.2. MOX fuel fabrication facility batch process data

Process	Process cycle data[a]	Data (average)
Receiving and storage	Plutonium throughput Cycle time Plutonium input form Plutonium output form	257 kg 1 month PuO_2 PuO_2
MOX fuel fabrication	Plutonium throughput Cycle time Plutonium input form Plutonium output form	3084 kg 1 year PuO_2 MOX fuel bundles
Bundle shipping	Plutonium throughput Cycle time Plutonium input form Plutonium output form	170 bundles 18.15 kg/per bundle 1 year MOX fuel bundles MOX fuel bundles

[a]Plutonium throughput represents amount of PuO_2 received in a single shipment. Cycle time represents interval between expected shipments of PuO_2.

fuel is sold, however, the MOX fuel fabrication life cycle advantage disappears when revenues are added. The total hybrid (32.5 MT of plutonium) MOX fabrication campaign costs $167M more than the five-PWR (50 MT of MOX) fabrication campaign described in Chap. 2. Table 6.3 shows the LCCs for the MOX fuel fabrication facility in 24-category format. The staffing for this 71.7-MTHM/year MOX fuel fabrication facility will be smaller than the PWR base-case MOX fuel fabrication facility: 81 direct FTEs (compared with 110) and 272 indirect FTEs (compared with 315). Thus, the total MOX fabrication facility staff requirement is 353 FTEs, compared with a total of 425 FTEs for the base-case five-PWR MOX fuel fabrication facility.

6.3.3 MOX Fuel Fabrication Facility Shipment and Storage

Following conversion to PuO_2 at the PuP facility, the PuO_2 will be repackaged (in the packages described in Appendix G) and shipped to the MOX fuel fabrication facility. This facility will operate on a schedule similar to the PWR operation schedule (~10+ years). This may still require that some of the PuO_2 be placed in a lead storage vault because the shipment campaign will be completed in 10 years. The lead storage vault could be accommodated in the design of the MOX fuel fabrication facility design, or any excess vault capacity at another DOE site could be used. Table 6.4 summarizes estimates of the number of packages and shipments required for this shipment leg. Shipment will be by SST. Each SST will transport between 28 and 35 packages containing PuO_2 with approximately three SSTs per convoy.

6.4 Hybrid PWR Facility

PWR Facility Description. The reactor facility description is the same as in Sect. 2.4.1 with the exception that only three PWRs will be used for the entire mission.

Three PWRs are specified for the mission because only 3 MT of the PuP facility annual output is designated for MOX fuel production. Also, the MOX fuel fabrication facility is reduced in size. It is not economically reasonable to construct a MOX fuel fabrication facility that would operate for a shorter time at the higher output rate used in the base case.

Table 6.5 lists the batch characteristics of each processing section of the reactor portion of this variant.

Information concerning the plutonium disposition rate for the reactors for this variant is shown in Table 6.6. Fuel cycle characteristics for the reactors are shown in Table 6.7. The MOX fuel charging and discharging schedule associated with the use of three Westinghouse reactors is shown in Table 6.8. For the reference MOX fuel, the annual disposition of plutonium for the three reactors would be 3.05 MT. The reload batch size for MOX fuel assemblies is 84. The average discharge exposure is 45 MWd/kgHM.

Table 6.3. LCCs for MOX fuel fabrication facility in 24-category format

Category	Cost category description	Lump sum (1996 $M)	Annual (1996 $M/year)
	Throughput = 71.7 MTHM/year Years of Operation = 10.7		
	Preoperational or OPC		
	Up-front costs:		
1	R&D	21	
2	NEPA, licensing, permitting	35	
3	Conceptual design	2	
4	Q/A, site qualification, S&S plans	1	
5	Postconstruction startup	41	
6	Risk contingency	0	
	TOTAL OPC	$100	
	Capital or TEC part of up-front cost:		
7	Title I, II, III engineering, design, and inspection	40	
8a	Capital equipment	125	
8b	Direct and indirect construction/modification	43	
9	Construction management	0	
10	Initial spares	10	
11	Allowance for indeterminates (AFI)	32	
12	Risk contingency	0	
	TOTAL TEC	$250	
	TOTAL UP-FRONT COST(TPC)	$350	
	Other LCCs (10.7 years of operations):		
13	Operations and maintenance staffing	294	27.5
14	Consumables including utilities	195	18.3
15	Major capital replacements or upgrades	129	12.0
16	Waste handling and disposal	44	4.1
17	Oversight	11	1.0
18	M&O contractor fees	13	1.3
19	Payments-in-lieu-of-taxes to local communities	7	0.6
	TOTAL ANNUAL RECURRING COSTS	$693	$64.8
20	D&D	50	
21	Revenues (if applicable) MOX or electricity	–925	–86.4
22	Fees to privately owned facility	0	
23	Transportation of plutonium forms to facility	18	1.7
24	Storage of plutonium at existing 94-1 site facility		
	TOTAL OTHER LCC	–$164	–$19.9[a]
	GRAND TOTAL ALL LCC (1996$M)	$186	

[a]Annual cost sum is $66.5M before revenues.

Table 6.4. Parameters for PuO_2 transport leg

Maximum plutonium/package (kg)	Quantity of plutonium/campaign (kg)	Estimated number of packages to be shipped	Number of SST shipments/campaign
4.5	32,500	20,150	715

Table 6.5. PWR facility batch process data

Process box	Process cycle data	Data (average)[a]
Fresh MOX fuel storage and handling	Plutonium throughput (kg)	1524
	HM throughput (MT)	35.4
	Cycle time[b] (years)	1.5
Irradiation in reactor	Plutonium throughput (kg)	1524
	HM throughput (MT)	35.4
	Cycle time (years)	4.5
Fuel storage pool (postirradiation)	Plutonium throughput (kg)	1067
	HM throughput (MT)	35.4
	Cycle time (years)	10.0
Dry storage of spent fuel	Plutonium throughput (kg)	1067
	HM throughput (MT)	35.4
	Cycle time[c] (years)	10.0

[a]Data given are per reactor.
[b]Fresh MOX fuel would reside in the fuel storage and handling facility for up to one full fuel cycle (1.5 years)
[c]Assumes that dry storage of the spent fuel is needed for the Westinghouse reactors for at least 10 years.

Table 6.6. Plutonium disposition capacity and rate for one reactor (Westinghouse)

Plutonium per assembly (kg)	18.15
Plutonium dispositioned per year (MT)	1
Plutonium dispositioned per cycle/reload	1.5

Table 6.7. Westinghouse MOX fuel cycle characteristics

Total cycle duration (d)	548
Effective full-power days per cycle (d)	438
Planned/unplanned outage time (d)	110
Reload batch size (assemblies)	84
Full core size (assemblies)	193
Average discharge exposure (MWd/kgHM)	45

Table 6.8. MOX fuel charging/discharging schedule employing three Westinghouse PWRs

Time from MOX load in first reactor (years)	Assemblies loaded in reactor				Cumulative plutonium loaded (MT)	Cumulative HM loaded (MT)	Cumulative assemblies discharged
	1	2	3	Cumulative			
0.0	84			84	1.52	35.4	
0.5		84		168	3.04	70.9	
1.0			84	252	4.57	106.3	
1.5	84			336	6.09	141.8	
2.0		84		420	7.62	177.2	
2.5			84	504	9.15	212.7	
3.0	84			588	10.67	248.1	
3.5		84		672	12.19	283.6	
4.0			84	756	13.72	319.0	
4.5	84			840	15.22	354.5	84
5.0		84		924	16.77	389.9	168
5.5			84	1008	18.29	425.4	252
6.0	84			1092	19.82	460.8	336
6.5		84		1176	21.34	4.96.3	420
7.0			84	1260	22.86	531.7	504
7.5	84			1344	24.39	567.2	588
8.0		84		1428	25.91	602.6	672
8.5			84	1512	27.44	638.1	756
9.0	84			1596	28.96	673.5	840
9.5		84		1680	30.49	709.0	924
10.0			84	1764	32.00	744.4	1008
10.5	27			1791	32.5	755.6	1092
11.0							1176
11.5							1260
12.0							1344
12.5							1428
13.0							1512
13.5							1596
14.0							1680
14.5							1764
15.0							1791

Notes:

1. Plutonium enrichment = 4.3%.
2. Plutonium per assembly = 18.15.
3. HM per assembly = 421.4 kg.
4. Assemblies per core = 193.
5. Reload batch size = 84 assemblies.
6. Plutonium dispositioned per year = 3 MT.
7. Reactor HM throughput per year = 69.5 MT (HM throughput for MOX facility production is 71.7 MTHM/year).
8. Cycle time is 4.5 years including allowance for 80% capacity factor.
9. Average discharge exposure = 45,000 MWd/MT.

6.4.1. Hybrid PWR Facility Schedule Summary

The existing PWR facility implementation activities for this variant are similar to those described in Sect. 2.4 (only for three reactors). The schedule for these activities is shown in Table 6.9. The first fuel will be loaded into a reactor in June 2007, and the last MOX fuel will be loaded in 2020. The irradiation campaign length for the hybrid variant is slightly longer (<1 year) than for the five-reactor base case.

6.4.2 Hybrid PWR Facility Cost Summary

Three PWRs have been specified for the hybrid variant. Because of a lower fee for three vs five reactors and only a slightly longer operating campaign (10.5 years vs 9.75 years), a cost savings for this facility of $227M will result compared with the five-reactor base case. Table 6.10 shows the LCCs in 24-category format. The staffing cost requirement for the reactor is based on 15 years (i.e., the first load in to last load out mission duration).

6.4.3 Hybrid PWR Facility Shipments and Storage

Approximately 1791 PWR MOX fuel assemblies will be fabricated from the 32.5 MT of plutonium. The MOX fuel assemblies will be shipped from the MOX fuel fabrication facility to the PWR facility.

Shipment Information. Table 6.11 provides estimates of the number of shipments required to transport the fresh MOX fuel from the fuel fabrication facility to the PWR facility.

6.5 HLW Repository

For a description of the HLW repository, see Chap. 2, Sect. 2.5.1. No changes in the design, construction, or operation of the facility are anticipated if this variant is selected.

6.5.1 HLW Repository Facility Schedule Summary

The overall HLW repository facility schedule for this alternative is the same as described in Sect. 2.5 except for the spent MOX fuel delivery schedule. The first spent fuel is scheduled to be delivered in December 2024, and the last spent fuel will arrive in June 2035. This schedule is shown in Table 6.1 and Fig. 6.5

6.5.2 HLW Repository Facility Cost Summary

The cost of the HLW repository facility for this variant is the same as the base case described in Sect. 2.5.6 (i.e., no incremental cost to the government is assumed).

Table 6.9. PWR facility schedule summary

Task name	Duration (months)	Start	Finish
FMDP Record of Decision			12/1996
Congressional Funding Approval Process	36	12/1996	12/1999
Utility Selection	12	12/1998	12/1999
Licensing and Permitting	51	12/1999	2/2004
Reactor Modifications	48	12/1999	12/2003
LUAs Arrive from MOX Fuel Fabrication Facility			6/2007
Fuel Qualification — LUAs	54	6/2007	12/2011
Unit 1 Loading Duration	126	5/2010	11/2020
Unit 2 Loading Duration	108	11/2010	11/2019
Unit 3 Loading Duration	108	5/2011	5/2020
Last Assemblies — First Cycle	18	11/2020	5/2022
Spent Fuel Storage	246	11/2014	6/2035

Table 6.10. LCCs for three reactor LWR facilities

Category	Cost category description	Three existing PWRs	
		Lump sum (1996 $M)	Annual (1996 $M/year)
	Years of operation = 10.5 for fee and transport; 15.0 for incremental staffing		
	Preoperational or OPC		
	Up-front costs:		
1	R&D	36	
2	NEPA, licensing, permitting	103	
3	Conceptual design	1	
4	Q/A, site qualification, S&S plans	2	
5	Postconstruction startup	22	
6	Risk contingency	0	
	TOTAL OPC	$164	
	Capital or TEC front-end costs:		
7	Title, I, II, III engineering, design, and inspection	8	
8a	Capital equipment	0	
8b	Direct and indirect construction/modification	33	
9	Construction management	0	
10	Initial spares (technology dependent)	0	
11	AFI	0	
12	Risk contingency	0	
	TOTAL TEC	$41	
	TOTAL UP-FRONT COST (TPC)	$205	
	Other LCCs:		
13	Operations and maintenance staffing (15 years)	63	4.2
14	Consumables including utilities		0.0
15	Major capital replacements or upgrades		0.0
16	Waste handling and disposal		0.0
17	Oversight		0.0
18	M&O Contractor fees		0.0
19	Payments-in-lieu-of-taxes to local communities		0.0
20	D&D (percentage of capital or dollar estimate)	0	
21	Revenues (if applicable) MOX or electricity	0	
22	Fees to privately owned facility (10.5 years)	270	25.7
23	Transportation of plutonium forms to facility (10.5 years)	26	2.5
24	Storage of plutonium at existing 94-1 site facility	0	
	TOTAL OTHER LCC	$359	32.4[a]
	GRAND TOTAL ALL LCC	$564	

[a]Annual reactor cost over first 10.5 years.

Table 6.11. Parameters for fresh MOX fuel transport leg

Maximum assemblies/package	Quantity of plutonium/ campaign (MT)	Estimated number of packages to be shipped	Number of SST shipments/campaign
Two PWR assemblies	32.5	910	910

6.6 Hybrid Variant Summary

6.6.1 Hybrid Variant Schedule Summary

The hybrid variant 32.5-MT case schedule is a combination of the individual facility schedules previously discussed. This overall schedule is summarized in Table 6.1 and shown in Fig. 6.5. The plutonium disposition mission begins when the first mission fuel is loaded into a reactor in May 2010 and is complete after the last core load, which contains MOX fuel assemblies, has been irradiated for a single cycle in May 2022. The overall mission time is 12 years and starts 13.5 years after ROD.

The critical path for this variant is the licensing, design, and facility modifications for the MOX fuel fabrication facility.

6.6.2 Hybrid Variant Cost Summary

Total cost for this variant is the sum of the individual facility cost.

PuP Facility Cost Summary. The cost of the PuP facility has yet to be accurately determined pending better facility throughput and design definition.

MOX Fuel Fabrication Facility Cost Summary. Use of the hybrid variant (three existing reactors) would reduce the before-revenue LCCs of the MOX fuel fabrication facility; however, these savings would be offset by the loss of revenue from the fuel displacement credit (i.e., less MOX fuel is sold to the power plant utility). The revenue effect on the MOX fuel fabrication facility depends on the LEU fuel equivalent price of MOX fuel received by the government. The net (after revenues) MOX-related cost is $167M higher than for the LWR base case as discussed in Sect. 6.3.2.

Reactors. It is anticipated that the reactor facility LCCs would be reduced by $227M compared with the five-PWR base case alternative, as discussed in Sect. 6.4.2.

Net effect of hybrid. Considering both the MOX fuel fabrication and reactor LCCs, the total reactor-related mission costs $60M less than the LWR base case, that is, the $227 reactor savings minus the $167M MOX fabrication loss compared with the base case. However, costs for the immobilization or borehole disposition facility (along with any related PuP costs) would have to be added to these reactor-related LCCs to obtain the total costs for the hybrid mission.

6.6.3 Hybrid Variant S&S Summary

With respect to the specific facilities and activities, there is no difference for this variant from the base case for S&S.

6.6.4 Existing LWR Hybrid Variant Technical Viability Summary

Technical viability issues of this variant are identical to those of the existing LWR base case (Chap. 2), except as noted in Appendix E.

6.6.5 Existing LWR Hybrid Variant Transportation Summary

Although only 32.5 MT of plutonium is involved in the reactor disposition portion of this variant, the transportation aspects of this case are identical to those described in the existing LWR base case. See Sect. 2.6.5 for additional information.

7. Existing LWR Alternative Summary

7.1 Existing LWR Alternative Summary Schedule

The plutonium disposition schedules for the four 50-MT existing LWR alternative variants are summarized in Table 7.1 and shown in Fig. 7.1.

The schedule risk for all of these alternatives is about the same. The PuP facility, MOX fuel fabrication facility, and HLW repository for the different variants are the same except for location and duration of operations. A similar schedule for utility selection and reactor facility modifications would be used for both PWRs and BWRs. The primary differences in the existing LWR schedules occur in the license modification process and the fuel loading schedule. There is a higher schedule risk in the license modification process for the existing LWRs that would use MOX fuel with integral neutron absorbers than for the LWRs that would use MOX fuel without integral neutron absorbers. However, this risk has been included in the schedules with a longer license modification procedure for the former case.

The critical path facility for all of the existing LWR variants except the Quick Start case is the MOX fuel fabrication facility. For the Quick Start case, the process to obtain a license for placing the LUAs in the core is the critical path. For the non–Quick Start cases, the start of the mission could be moved one irradiation cycle earlier with the use of European LUAs if the fuel design did not include integral neutron absorbers.

Table 7.1. Existing LWR disposition alternative schedule summary

	Option			
	Base case	Private MOX	Collocated PuP and MOX fuel fabrication facility	Quick Start
PuP facility				
Prototype start				1/1998
Start processing at production facility	7/2006	7/2006	6/2007	7/2006
MOX fuel fabrication facility				
Start LUA fabrication	12/2006	12/2006	7/2007	4/2000
Mission fuel fabrication start	6/2007	6/2007	12/2007	3/2001
Mission fuel finish	4/2017	4/2017	7/2023	12/2015
Reactor facilities				
Reactor type	PWR	PWR	BWR	PWR
Reactor "ready" to receive MOX	2/2004	2/2004	3/2005	2/2004
Start irradiating European LUA				12/2002
Start irradiating American LUA	6/2007	6/2007	12/2007	6/2007
Mission start	5/2010	5/2010	4/2010	11/2005
Last assembly loaded	3/2020	3/2020	10/2026	1/2019
Mission finish	8/2021	8/2021	12/2027	7/2020
Mission duration (years)	11.3	11.3	17.7	14.6
ROD to mission start (years)	13.5	13.5	13.3	9.0

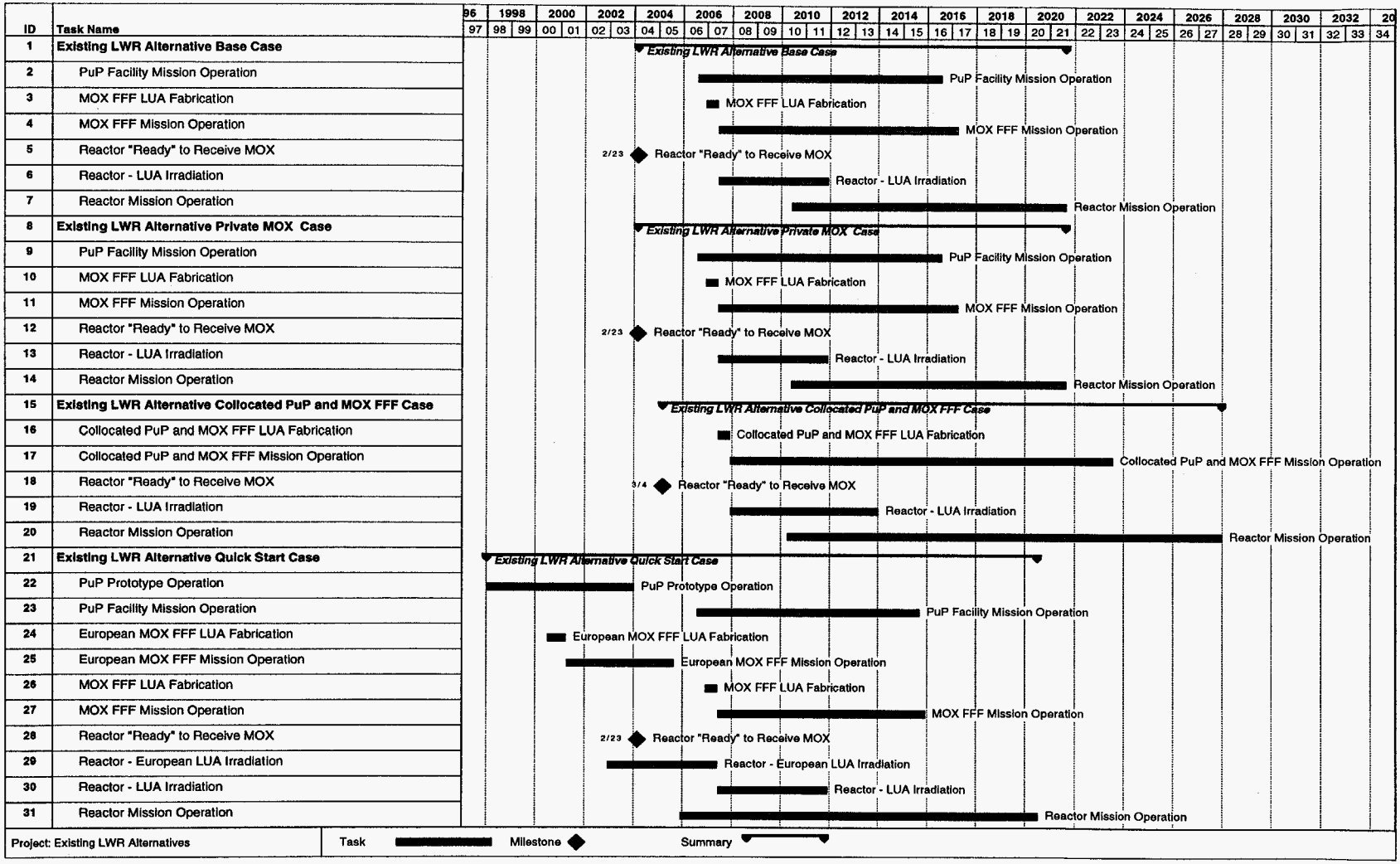


Figure 7.1. Existing LWR alternatives schedule summary

7.2 Existing LWR Alternative Cost Summary

Table 7.2 shows a comparison of LCCs for all of the LWR alternatives. For the hybrid case, only the costs related to MOX fuel production and the reactors are shown. The PuP LCCs and any appropriate immobilization costs will be analyzed as this alternative becomes better defined.

Of all the existing LWR variants, the base case has the lowest overall cost. The private MOX fuel fabrication facility case has lowest up-front cost; however, the overall LCC is higher because of the interest and investment returns required for privatization of the MOX fuel fabrication facility enterprise. With new PuP and new greenfield MOX collocated facilities, the four-BWR case has the highest up-front cost. The overall LCC, however, is less than $200M greater than the base case. The schedule advantages of the Quick Start case come at a cost of less than $205M over the base case.

Table 7.2. Comparison of LCCs for existing LWR reactor variants

RASR cost category description	Chap. 2—five-LWR base case (50SFL5)	Chap. 3—base case with private MOX fab (50SPL5)	Chap. 4—four-BWR case with new collocated PuP/MOX (50COL4)	Chap. 5—five-PWR base case with Quick Start (50QSL5)	Chap. 6—three-PWR hybrid (reactor and MOX costs only, no immobilization or plutonium processing) (33SFL3)[a]
Undiscounted costs (constant 1996 $M)					
Up-front (investment) cost for all facilities	954	554	1378	980	555
Operations costs including transportation for all facilities	1995	1075	2114	1855	800
D&D costs for all relevant facilities	229	169	456	229	50
Incentive fee (to reactor owners)[b]	433	433	482	515	270
Revenues from sale of MOX at LEU equivalent price	–1387	–1387	–2006	–1387	–925
Payment for EuroMOX fabrication	0	0	0	237	0
Payment for private U.S. MOX fabrication	0	2007	0	0	0
Total LCC	$2224	$2851	$2424	$2429	$750
Discounted costs (constant 1996 $M)					
Up-front (investment) cost for all facilities	687	400	953	706	400
Operations costs including transportation for all facilities	965	528	895	970	360
D&D costs for all relevant facilities	83	62	147	89	17
Incentive fee (to reactor owners)[a]	231	204	173	229	115
Revenues from sale of MOX at LEU equivalent price	–658	–597	–817	–725	–431
Payment for EuroMOX fabrication	0	0	0	173	0
Payment for private U.S. MOX fabrication	0	863	0	0	0
Total LCC	$1308	$1460	$1351	$1442	$461

[a]Chapter 4.5 of the July 17 TSR discusses the total cost of the three-PWR hybrid option using can-in-canister immobilization as the deposition option for the 1.5 MT of plutonium not going to the reactor option.
[b]Not included in TSR.

7.3 Existing LWR Alternative S&S Summary

DOE and its predecessor agencies have successfully managed safeguards and security of SNMs for several decades. DOE maintains an impeccable record of providing adequate measures to ensure against theft or unauthorized access to SNMs. These measures include physical security, material accountability, inventory safeguards, and other technologies. These measures have been applied to SNMs in a variety of material forms, ranging from bulk SNM powders and solutions to pits.

An assessment has been performed to identify where critical vulnerabilities might exist in operations or processes that make up the reactor disposition alternative. The purposes of the assessment were to (1) determine whether any inherent vulnerabilities exist that represent unique or novel threats to maintaining adequate measures against theft or unauthorized access and (2) identify any threats in the reactor disposition alternative operations that will require particular attention by facility designers to ensure that potential vulnerabilities are properly addressed.

The potential risks are presented in Table 7.3. In the sense employed here, a risk is a set of conditions that require specific measures to ensure proper physical control of SNMs. These risks should *not* be interpreted as the overall risk to which the material will be subject in the as-built facilities. The overall risk in the as-built facility is driven to very small values by the S&S measures incorporated in the design and operation of the facility. This assessment is based on available data and on the inherent risk for each of the measures. The facilities with the highest and least risk were common to all alternatives. The PuP facility has the highest risk while the repository has the lowest. Risk remains relatively high until the MOX fuel has been irradiated. The collocated LWR variant has one less transport leg and therefore has the least transport risk.

The final disposition form for all the existing LWR variants meets the SFS. Because the radiological barrier is time dependent, it will, over a long period of time, decrease and the material will at some point no longer be self-protecting. Therefore, it is necessary for long-term disposition that the material also be made as inaccessible as possible and that appropriate safeguards remain in place.

No unique or novel threats are presented by the reactor disposition alternative that would jeopardize DOE's ability to ensure control of SNMs. Similar or identical processing operations have been successfully accomplished in the DOE complex over the last 40 years. On the other hand, several vulnerabilities associated with the disposition alternatives have been identified that will require proper attention in facility design and operations. Most of these vulnerabilities relate to the handling of large amounts of SNM in attractive bulk form. These vulnerabilities require that measures be applied to ensure proper safeguards against theft or unauthorized access. In all cases, the overall risk of theft or unauthorized access to material would be very low.

7.4 Existing LWR Alternative Technical Viability Summary

The PuP facility is the least viable component of any of the existing LWR facilities. This observation is a deciding factor in ranking technical viability among existing reactor alternatives. The Quick Start variant and the collocated variant using integral burnable absorbers were judged to have lower technical viability than the other existing LWR variants. The Quick Start variant relies on the success (meaning that no modifications beyond those considered here would be required) of the yet-to-be-demonstrated ARIES process. Very little time is provided in the initial startup phase of this variant for the substitution of other processes should product from the ARIES process prove unacceptable. Likewise, the schedule for any variant (such as the collocated variant) that employs integral neutron absorbers in the fuel is dependent on the successful development of the as-yet-unmanufactured MOX integral burnable absorber. Additional time would be required should the need arise for a substitute (different integral neutron absorber, different production method, or substitution of a fixed neutron absorber).

The reactor portion of the hybrid option is only slightly less viable than some of the 50-MT variants. This anomaly is a result of the reliance of some of the 50-MT variants on both the ARIES process and the aqueous processes for supply of reactor fuel. The hybrid variant relies solely on the less-developed ARIES process for supply of PuO_2 to the MOX fuel fabrication facility and thus incurs some additional, but difficult to quantify, risk.

Table 7.3. Potential risks for theft, diversion, and retrieval

	Plutonium conversion	Transit	MOX fuel fabrication	Transit	Reactor	Transit	Repository
Threat							
Covert threat (domestic)	High	Medium	High/Low	Low	Low/Low	Low	Low
Overt threat (domestic)	Medium high	Medium	Medium high/Medium	Medium	Medium/Low	Low	Low
Diversion (international)	High	Medium	High/Medium	Medium	Medium/Low	Low	Low
Risk from unauthorized parties							
Material form	High	High	High/Medium	Medium	Medium/Low	Low	Low
Environment	High	Medium	High/Medium	Medium	Medium/Medium	Medium	Medium/Low
Safeguards and security	High	Medium	High/Medium	Medium	Low/Low	Low	Low
Risk from host nation							
Detectability	High	High	High/Medium	Medium	Medium/Low	Low	Low
Irreversibility	High	Medium	High/Medium	Medium	Medium/Low	Low	Low

Though fabrication technology is well known, several issues unique to the plutonium disposition program remain to be resolved. Because the reactors currently operate with fuel having similar extended burnup cycles, viability issues related to the reactor and repository are minor. Furthermore, these issues should be resolvable within the time it takes to construct and license the PuP facility and MOX fuel fabrication facility. Consequently, the program mission would not be impacted.

The technical risks involved with these alternatives result in scheduling and economic uncertainties. *There is no question that reactor-based plutonium disposition technologies are feasible.* Nevertheless, the time—and even the need—to implement certain technologies is uncertain. It is virtually certain that the program disposition goal is attainable; however, the amount of development work required is uncertain. The risk of not meeting the program goal increases, but by an unknown amount, if the development work is not appropriately pursued.

There is no question that reactor-based plutonium disposition technologies are feasible.

7.5 Existing LWR Alternative Transportation Summary

Multiple facilities are required for disposition of 50 MT of excess weapons-usable plutonium as MOX fuel in an LWR. The plutonium moves sequentially between each facility (described previously) from its present locations (storage vaults at a number of DOE facilities) through the various processing, fabrication, and reactor facilities, and ultimately, to emplacement as spent fuel at an HLW repository. Figure 7.2 provides a simplified flowchart of the transportation segments associated with the existing LWR disposition alternative. Actual facility locations will be determined by DOE following the ROD.

For analysis purposes, it has been assumed for the existing LWR alternative that the excess plutonium is in interim storage at many locations within the DOE weapons complex. This material is first packaged and transported to a PuP facility (assumed to be located at SRS), where the material is converted to PuO_2. The PuO_2 is then repackaged and transported to the MOX fuel fabrication facility. Once fabricated, the fresh MOX fuel is packaged and transported to the LWR facility. These reactors are assumed to be privately owned and constructed on an existing federal site.

Spent fuel discharged from each reactor is first stored in spent fuel pools at each reactor for 10 years. Ultimately, the spent fuel is packaged and transported to an HLW repository for emplacement in a geologic repository.

7.6 Other Benefits

7.6.1 Reduction of Plutonium Inventory from Reactor-Based Disposition Alternatives

Four different classes of reactor-based disposition alternatives are under consideration: (1) existing LWRs, (2) existing CANDU HWRs, (3) partially complete LWRs (completed and operated for the plutonium disposition mission), and (4) new ELWRs. All reactor alternatives offer two important advantages for plutonium disposition. First, a portion of the initial 50 MT of plutonium is consumed in the reactor (converted by fission to energy, which is in turn converted to electricity). Second, the plutonium that remains is converted from weapons-grade (isotopic purity of 94% fissile ^{239}Pu) to reactor-grade (fissile fraction of ^{239}Pu between 55 and 65%).

Of the four classes of reactor-based disposition alternatives noted previously, the alternatives that use existing reactors (LWRs or CANDU HWRs) offer the additional advantage of displacing uranium-based fuels from these reactors that would otherwise have resulted in creation of additional reactor-grade plutonium. Table 7.4 shows a summary of plutonium inventories before and after reactor-based disposition. On average, all reactor alternatives convert the 50 MT of weapons-grade plutonium into about 35 MT of reactor-grade plutonium contained within the spent fuel (see Fig. 7.3). Existing reactor alternatives (LWR or CANDU) have the added benefit of avoiding the creation of between 12.5 and 14.7 MT of plutonium from their operation on an LEU fuel cycle, for a net plutonium reduction inventory of between 26 and 30 MT. *Clearly, the reduction of overall plutonium inventory is a favorable outcome of the reactor-based alternatives that is not achievable by immobilization or deep borehole disposition alternatives.*

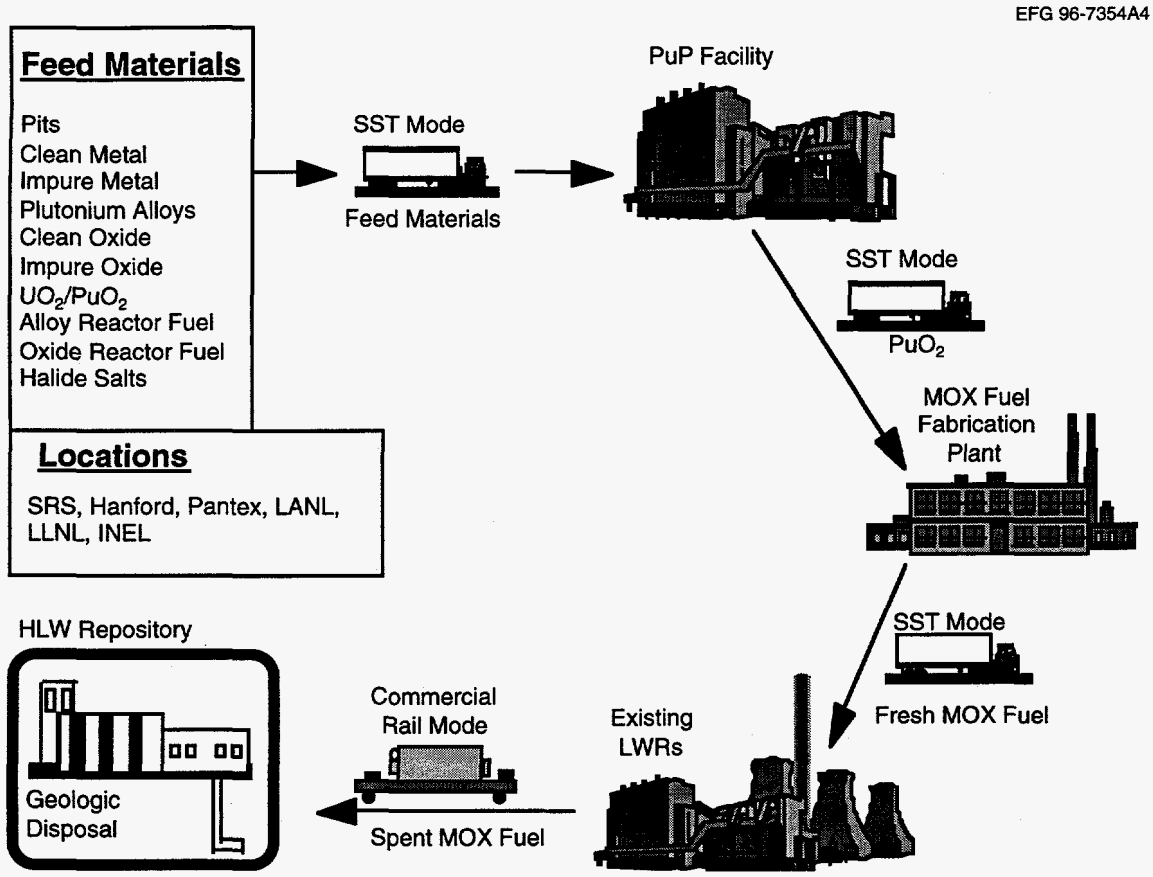


Figure 7.2. Simplified flowchart showing transportation segments for the existing LWR alternative

Table 7.4. Plutonium inventory reduction for reactor-based disposition alternative

Alternative	Without reactor disposition (MT)			After reactor disposition (MT)			Net plutonium inventory reduction (MT)
	Weapons-grade plutonium	Reactor-grade plutonium[a]	Total	Weapons-grade plutonium	Reactor-grade plutonium	Total	
Existing LWRs	50	14.7	64.7	0	35.0	35.0	29.7
CANDU HWRs	50	12.5	62.5	0	36.9	36.9	25.6
Partially complete LWRs	50	0	50	0	36.8	36.8	13.2
ELWRs	50	0	50	0	36.4	36.4	13.6

[a]Reactor-grade plutonium that would be produced from UO_2 fuels in the mission reactors during the mission period if a nonreactor disposition alternative were employed.

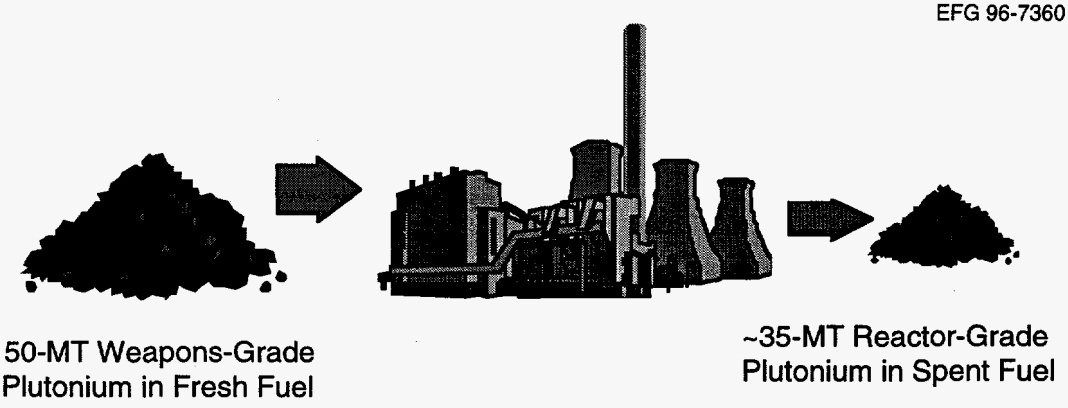


Figure 7.3. Depiction of consumption of plutonium by reactor alternatives

7.6.2 Reduction of Health Impact of Uranium Fuel Cycle

The existing LWR alternative has as an important attribute: it reduces the health impacts associated with existing uranium fuel cycle facilities. The activities associated with the conversion of surplus plutonium into MOX fuel will replace activities associated with the current nuclear fuel cycle. This results in less uranium being mined, processed, and enriched. Additionally, the operation of the MOX fuel fabrication plant that produces 118 MTHM of fresh fuel per year will displace the production of 118 MTHM of fresh LEU fuel from existing fuel fabrication facilities. Although environmental impacts will accrue from operation of the pit disassembly/plutonium conversion plant and the MOX fuel plant, these impacts are expected to be more than offset by the environmental benefits of reducing the uranium processing activities in the existing nuclear fuel cycle facilities.

In the United States, the uranium nuclear fuel cycle for commercial nuclear power plants begins with mining ore and ends with the disposal of the final radioactive wastes. The typical uranium fuel cycle for LWRs in the United States is described in Table 7.5. The MOX fuel cycle steps for proposed reactor alternatives are also listed in the table for comparison. Pit disassembly and plutonium conversion will replace the current uranium fuel cycle steps from uranium ore mining through uranium enrichment (steps 1 through 4). The nuclear fuel fabrication and burning in reactors also will be slightly different.

In the LWR uranium fuel cycle, the most significant contributors to the adverse impact on human health and the environment are uranium mining, milling, and conversion (from U_3O_8 to UF_6). The remaining nuclear fuel cycle processes (enrichment and fuel fabrication) have considerably lower radioactive emissions than the significant contributors. In the draft PEIS, the MOX fuel cycle operations are calculated to result in 3.6 to 9.4 latent cancer fatalities during the baseline existing LWR campaign. The displaced uranium operations would have resulted in 16 to 22 latent cancer fatalities.

Table 7.5. Comparison of uranium fuel cycle and MOX fuel cycle

Step	Uranium fuel cycle	MOX fuel cycle
1	Uranium mining	Pit/disassembly and plutonium conversion
2	Uranium milling	
	Uranium conversion to UF_6	
4	Uranium enrichment	
5	Uranium preparation and uranium fuel element fabrication	MOX fuel element fabrication
6	Nuclear power plants fueling—irradiation in the reactor	Nuclear power plants fueling—irradiation in the reactor
7	Spent fuel storage	Spent fuel storage

In addition to the radiological health effects documented in the draft PEIS, significant nonradiological occupational health impacts are associated with uranium mining. Fatal and nonfatal accident rates for underground uranium mining are well established, as are the rates of occupational illnesses such as scoliosis, vibratory-induced joint disorders, and respiratory disfunction.

The replacement of some uranium fuel cycle operations with MOX fuel cycle operations will also avoid the creation of two difficult radioactive waste streams: uranium mill tailings and depleted uranium. *The existing LWR alternative displaces uranium enrichment activities that would create 4,000 to 10,000 MT of depleted uranium.* Strategies for disposition of depleted uranium are under study by the DOE Office of Nuclear Energy, Science and Technology. Decisions have not yet been made that would allow quantitative assessment of the benefits of avoiding this quantity of depleted uranium. *The reduction in uranium mining activities would result in a decrease of 4 to 15 million tons of uranium mill tailings.* The radiological impacts of the mill tailings are included in the health impacts previously cited, but nonradiological impacts of milling tailings also exist and are difficult to quantify. Principal nonradiological impacts are the permanent loss of many acres of land used for long-term storage of the mill tailings piles, and the changes in local and regional water quality caused by minerals that leach from the piles.

The decrease in uranium enrichment activities associated with MOX fuel for existing LWRs will result in the conservation of the electricity that would have been consumed by the gaseous diffusion plants (GDPs) during the enrichment step. For the existing LWR alternative, the electricity conserved per year would be between 200 and 350 MW-year. The health impacts of the coal-fired power plant operations that provide electricity to the GDPs would also be reduced.

In summary, a notable aspect of the existing LWR alternative is that the operations of the MOX fuel cycle facilities replace the operations of existing front-end uranium fuel cycle facilities. *Mining fissile material from the plutonium-based pits of nuclear weapons is expected to have far fewer health and waste stream impacts than the uranium mining and fuel cycle operations that would be displaced.*

7.6.3 Beneficial Use of Depleted Uranium

The existing LWR alternative involves the use of approximately 700 MT of depleted uranium in the manufacture of MOX fuel. The current inventory of DOE-owned depleted uranium is about 375,000 MT existing in the form of UF_6 that is stored within canisters at DOE reservations in Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. These canisters are stored on concrete pads exposed to the weather, and concerns about potential canister corrosion and UF_6 releases have been raised by many sources. DOE's Office of Nuclear Energy, Science and Technology is currently studying disposition alternatives for the existing inventory of depleted uranium. Disposal of depleted uranium in near-surface or subsurface facilities is a primary option, but beneficial uses for depleted uranium are being sought as a way to avoid the costs and long-term radiological emissions associated with classifying the depleted uranium as waste.

Mining fissile material from the plutonium-based pits of nuclear weapons is expected to have far fewer health and waste stream impacts than the uranium mining and fuel cycle operations that would be displaced.

Disposal costs of the depleted uranium, once it has been converted to a uranium oxide form, have been estimated to be in the range of $5/kg to $25/kg.[1] *Thus, the beneficial use of depleted uranium in MOX fuel may avoid waste disposal costs totaling $3.5M to $17.5M.* These cost benefits are not included in the overall financial summaries for this alternative because of the uncertainties associated with the future strategy for depleted uranium disposition.

7.6.4 Influences on Russia and Other Countries

In view of the mutual desire of the United States and Russia to facilitate disposition activities, it is essential for the United States to set appropriate standards and to promote timely implementation of secure monitoring regimes and ultimate disposition of nuclear materials in Russia and other countries. Russian officials have indicated their preference for reactor-based plutonium disposition technologies in several

international forums. The existence of critical elements of the reactor-based plutonium disposition infrastructure in both countries would facilitate rapid mutual progress should the United States select the reactor-based plutonium disposition approach.

7.6.5 Generation of Electrical Energy from Reactor-Based Disposition Alternatives

Large quantities of electrical energy would be produced from disposition of 50 MT of plutonium if a reactor-based alternative were to be implemented. Approximately 2.3 to 5.1×10^{11} kWh of electrical energy would be produced from MOX fuel. This is enough electrical energy to meet the present-day electrical demand of Boston, Massachusetts, and much of the surrounding area (1.5 million people, 600 miles^2) for about 18 to 40 years, or of the entire state of Massachusetts for 8 to 18 years. The hybrid case, for which 32.5 MT of plutonium is incorporated into MOX fuel for use in three LWRs, would produce approximately 2.9×10^{11} kWh, which could meet the Boston-area electrical demand for about 21 years or the demand for all of Massachusetts for 9 years.

7.7 Reference

1. National Academy of Sciences, *Affordable Cleanup? Opportunities for Cost Reduction in the Decontamination and Decommissioning of the Nation's Uranium Enrichment Facilities*, Academy Press, 1966.

Appendix A
Summary Description of Plutonium Disposition Reactor Alternatives and Variants

As described in Chap. 1, five basic reactor-based plutonium disposition alternatives survived the screening process, of which one, the EuroMOX alternative, was subsequently dropped from further consideration (Table A.1).

Regardless of the reactor alternatives (LWRs, CANDUs, etc.) under consideration, multiple process or facility variations are possible at several points in the material flow (Fig. 1.1). Each of these end-to-end process and facility chains or "variants" constitutes a unique approach to the plutonium disposition mission. Thus, an "alternative" is a group or class of variants that share a generic reactor type (existing LWRs, CANDUs, etc.).

The number of potentially viable variants for any one of the four reactor alternatives was too large for individual analysis of each combination (Table A.2). To limit the scope of the study to a tractable level, a "base" or "reference" case was selected for each of the four reactor alternatives. The base cases were defined simply to be reasonable initial cases to facilitate the analysis. Other variants within the alternative were considered for analysis only if they were perceived to be significantly different from the base case and to have some advantage over it. Quantitative criteria or "variant discriminators" were required to implement this definition and to select the variants to be analyzed for each reactor alternative. Five "variant discriminators" were ultimately adopted by the Reactor Alternative Team (RxAT) (Table A.3). A variant was analyzed if it was anticipated that any one of these five criteria would be met, with the exception of the hybrid alternatives.

A.1 Introduction of Options

Based on the variant selection approach outlined above, ten reactor-based plutonium disposition scenarios were initially selected for further analysis. One

Table A.1. Plutonium disposition reactor alternatives

Alternatives		PuP/MOX fabrication facility	Type of reactors	Number of reactors	Integral neutron absorbers
Existing LWRs	Existing facilities	Existing facilities on DOE site	PWR	5	No
	New facilities	New collocated plutonium processing facility and MOX fabrication plant	BWR[a]	4	Yes
Partially complete LWRs		Existing facilities on DOE site	PWR	2	Yes
Evolutionary LWRs		Existing facilities on DOE site	PWR	2	Yes
Existing CANDUs		Existing facilities on DOE site	CANDU	2 for 5 years on reference fuel, then 4 reactors on advanced fuel (CANFLEX)	No

[a]BWRs could also be implemented using existing facilities and without integral neutron absorbers. The facility combinations considered were done only for the purpose of producing bounding scenarios. The decision at ROD would not down select between PWRs and BWRs if the existing reactor alternative is selected.

Table A.2. Deployment approaches for LWRs

Parameter	Range of possible choices	Comments
PuP facility	• Greenfield—new facility at a new site • New facility at a DOE site • Existing facility at a DOE site	All three options could also be done either in conjunction with (cofunctional, collocated facilities) or separate from a MOX fuel fabrication facility
MOX fuel fabrication facility	• Ownership—privately-owned domestic, government-owned domestic; existing European facilities • Siting—greenfield, new facility at a DOE site, or an existing facility at a DOE site	Except for the European cases, all options could also be done in conjunction with or separate from a plutonium processing facility. (It is likely that plutonium processing would remain government owned)
Type of reactor	PWRs and BWRs	Even for a specific type of reactor, many designs are available. Both types could operate with or without integral neutron absorbers
Number of reactors	2–5[a]	Two is the minimum number of reactors. The maximum number of reactors is limited to the number of reactors available
Core design approaches	• Amount of MOX per core—full-core with neutron absorbers, full core without neutron absorbers, partial MOX cores • Irradiation—from 10,000–45,000 MWd/MTHM (approximately) • Fuel cycle length—12, 18, and 24 months	

[a]The five-PWR choice is similar to the four-BWR choice for environmental impacts.

Table A.3. Reactor variant discriminators

Variant discriminator number	Description
1	The *start time* for plutonium disposition for the proposed variant decreases by three or more years from the base case
2	The *duration* of the plutonium disposition mission decreases from that of the base case by five or more years
3	The *investment cost* before initial plutonium disposition for the proposed variant is at least $500M less than the base case
4	The *discounted life cycle* cost for a proposed variant is at least $500M less than the base case
5	The proposed variant involves *facilities in a foreign nation*

of these options (EuroMOX) was eventually deemed to be unworkable (see Sect. A.1.5). The current alternative/variant set (Tables A.4 and A.5) consists of the existing LWR base case, three variants, and a hybrid case; the CANDU case and one hybrid case; a partially complete LWR case; and an ELWR case.

Table A.6 provides summary information of the plutonium throughput characteristics for each reactor alternative and variant.

[**Note:** *None of these reactor-based plutonium disposition alternatives have been optimized in terms of cost,*

Table A.4. Reactor alternatives and variants—50-MT cases

ID	Category	Description
50SFL5	Existing LWR base case	• 50 MT of plutonium • Plutonium processing — Halide plutonium processing at LANL — Modified existing 221-F plutonium processing facility (ARIES and new aqueous lines) at SRS • MOX fabrication — Domestic, federally owned, GoCo fuel fabrication facility located in existing building on existing federal site • Reactors — Five privately owned domestic PWRs — Core loading using the maximum MOX possible without integral neutron absorbers (full MOX cores) • Spent fuel to HLW repository in United States
50SPL5	Existing LWR Variant 1	Same as 50SFL5 (LWR base case) except: • Privately owned MOX fuel fabrication facility located in a new building on an existing federal site
50COL4	Existing LWR Variant 2	Same as 50SFL5 (LWR base case) except: • Federally owned, collocated plutonium processing and MOX fabrication facility located in a new building on an existing federal site • Four privately owned BWRs • Core loading using the maximum MOX possible with integral neutron absorbers (full MOX cores)
50QSL5	Existing LWR Variant 3	Same as 50SFL5 (LWR base case) except: • Plutonium available from ARIES demonstration and prototype operation • Early MOX fabrication in existing European commercial facilities • Lag storage facility added for fresh MOX fuel
50SFP2	Two partially complete LWRs	Same as 50SFL5 (LWR base case) except: • Two partially complete federally owned PWRs are completed and employed for mission • Core loading using the maximum MOX possible with integral neutron absorbers (full MOX cores)
50SFE2	Two new evolutionary LWRs	Same as 50SFL5 (LWR base case) except: • Federally owned reactors located on an existing federal site • Core loading using the maximum MOX possible with integral neutron absorbers (full MOX cores)
50SFC2-4	CANDU base case	Same as 50SFL5 (LWR base case) except: • Two CANDU units operated on reference CANDU fuel for 5 years followed by • Four CANDU units operated on CANFLEX fuel for 7.2 years

Table A.5. Reactor alternatives and variants—33-MT hybrid cases

ID	Category	Description
33SFL3	Hybrid LWR	Same as 50SFL5 (LWR base case) except: • 32.5 MT of plutonium • Three PWRs
33SFC2	Hybrid CANDU	Same as 50SFC2-4 (CANDU base case) except: • 32.5 MT of plutonium • Two CANDU units operated on reference fuel for the entire mission

schedule, or any other characteristic. The analyses discussed in this report include the evaluation of site-specific issues (such as transportation costs, etc.). It was necessary to associate each facility with a geographical site to facilitate these analyses. The selection of these "surrogate" sites should in no way be interpreted as a prediction or a recommendation for the actual site of these facilities.]

A.1.1 Existing LWR Alternative

The existing LWR alternative employs existing domestic LWRs for irradiation of the surplus plutonium. The actual numbers and types of reactors potentially available for the plutonium disposition mission in the United States are varied and extensive. The U.S. commercial reactor population consists of several different vintages/models of reactors, produced by four different reactor vendors. The base case (50SFL5) chosen by the RxAT consists of five Westinghouse pressurized water reactors (PWRs).

50SFL5—Existing LWR Base Case—This case is for the disposition of 50 MT of plutonium. The plutonium processing facilities consist of two federally owned facilities, one for halide plutonium processing at Los Alamos National Laboratory (LANL) and one using ARIES and aqueous plutonium processing at SRS. MOX fuel will be fabricated in a federally owned facility located on a federal site in an existing building. Five existing privately owned PWRs will be used to transform the MOX fuel to a form meeting the SFS. Spent fuel will be sent to an HLW repository. Fuel will *not* contain integral neutron absorbers.

50SPL5—Existing LWR Variant 1—This case is identical to Case 50SFL5, except the MOX fuel fabrication facility is a privately owned new building on an existing federal site.

50COL4—Existing LWR Variant 2—This case is identical to Case 50SFL5, except the plutonium processing and MOX fuel fabrication facilities are federally owned, cofunctional, collocated facilities located in a new building on an existing federal site. Fuel with a maximum plutonium loading and integral neutron absorbers is loaded into four privately owned BWRs.

50QSL5—Existing LWR Variant 3—This case is identical to Case 50SFL5 except plutonium will be made available from the ARIES demonstration and prototype operations. Early MOX fuel (before the domestic MOX fuel fabrication facility is operational) will be provided by European commercial MOX facilities. A lag storage facility will be needed for fresh MOX fuel.

33SFL3—Hybrid LWR—This case is identical to Case 50SFL5 except three existing privately owned PWRs will be used to transform 32.5 MT of plutonium in the form of MOX fuel to a form meeting the SFS. This "hybrid" approach consists of using three LWRs in conjunction with another disposition technology (vitrification or deep borehole technology) to disposition the entire inventory of surplus plutonium. Vitrification or deep borehole technology would be used to disposition the remaining 17.5 MT of surplus plutonium.

A.1.2 CANDU HWR Alternative

50SFC2-4—CANDU—This case is identical to the existing LWR base case except the reactors will be two CANDU units operated on reference CANDU fuel for 5 years followed by four CANDU units operated on CANFLEX (extended burnup) fuel for the remainder of the mission. This case uses existing CANDU reactors at the Bruce A Site in Ontario, Canada.

33SFC2—Hybrid CANDU—This case is identical to Case 50SFC2-4 except two CANDU units operated on

Table A.6. Summary of throughput characteristics for plutonium disposition reactors

ID number	Reactors	Loading time[a] (years)	Plutonium in HM (%)	Reactor initial loading (MT)		Reactor average[c] plutonium throughput (MT/year)	Reactor average[d] MOX (HM) throughput (MT/year)	Burnup (MWd/MT)
				Plutonium	HM[b]			
50SFL5	Five PWRs	9.8	4.3	1.52	35.4	5.0	118.2	45,000
50SPL5	Five PWRs	9.8	4.3	1.52	35.4	5.0	118.2	45,000
50COL4	Four BWRs	16.55	3.0	0.94	31.2	3.0	98.8	33,700
50QSL5	Five PWRs	13.1	4.3	0.5	10.6	5.0	118.2	45,000
50SFP2	Two partially complete PWRs[e]	15.12	4.5	3.17	105.8	3.0	67.7	32,500
50SFE2	Two ABB-CE System 80+ PWRs	13.3	6.8	6.7	98.2	3.5	52.2	42,600
50SFC2-4	Two Bruce A CANDU reactors for 5 years, then four Bruce A CANDU reactors with CANFLEX for 7.2 years	12.3	2.2[f] 3.4[f]	2.9	138.1	2.9 5.0	136.1 149.9	9,700 17,100
33SFL3	Three PWRs	10.5	4.3	1.52	35.4	3.0	69.53	45,000
33SFC2	Two Bruce A CANDU reactors	11.8	2.2[f]	2.9	138.1	2.9	138.1	9,700

[a]The loading time is the period between the initial MOX loading into the first reactor and the final MOX loading into the last reactor.

[b]Since initial loads for options 50SFP2, 50SFE2, 50SFC2-4, and 33SFC2 are full core, plutonium and HM throughputs represent full core load.

[c]The average plutonium throughput is the mass of plutonium loaded after the initial loading of the first reactor divided by the mission time.

[d]The average HM throughput is the plutonium throughput divided by the plutonium in HM.

[e]The partially complete reactor schedule is represented by the throughput for two ABB-CE System 80 reactors. It should be noted that the initial cores for this case employ a 3.0% plutonium enrichment.

[f] For CANDU and CANFLEX, the listed plutonium enrichment is the weighted average for the pins that contain plutonium.

reference CANDU fuel would be used to disposition 32.5 MT of plutonium. This "hybrid" approach consists of using two CANDU reactors in conjunction with another disposition technology (vitrification or deep borehole technology) to disposition the entire inventory of surplus plutonium. Vitrification or deep borehole technology would be used to disposition the remaining 17.5 MT of surplus plutonium.

A.1.3 Partially Complete LWR Alternative

50SFP2—Partially complete LWR—This case is identical to the existing LWR base case (50SFL5) except the reactors will be two newly completed, federally owned PWRs (currently privately owned and partially complete). Fuel will contain integral neutron absorbers.

A.1.4 Evolutionary Reactor Alternative

50SFE2—Evolutionary LWR—This case is identical to the existing LWR base case except the reactors will be two newly completed, federally owned evolutionary reactors constructed on an existing federal site. Fuel will contain integral neutron absorbers.

A.1.5 EuroMOX—The Elusive Option

The EuroMOX alternative involves the preparation of plutonium oxide at a new GoCo PuP facility to be built in the United States and transportation of the oxide to Europe, where it would be fabricated into MOX reactor fuel assemblies (Table A.7) and used as full-core MOX fuel loading in existing European reactor facilities. Final emplacement of the spent fuel assemblies would be in one or more HLW repositories in Europe.

During the course of this study, it became clear that none of the existing European MOX fuel fabricators are willing to act as an entry point for American weapons-grade MOX into the European commercial MOX economy. Thus, an immediate and seemingly insurmountable obstacle to implementation of this alternative became apparent. Additionally, the desire for timely disposition of the weapons-grade plutonium would require either the relicensing of two or more foreign reactors for full-MOX cores, or the use of several foreign reactors with partial-MOX cores. It is possible that multiple reactors in more than one European country would be required to implement this alternative. The MOX fabricators' unwillingness to participate in this endeavor combined with the political and institutional difficulties associated with its implementation effectively eliminate EuroMOX from consideration as a viable alternative.

A.2 European Fabrication of MOX Fuel

As shown in Table A.7, MOX fuel fabrication capacity is growing rapidly in Europe. The increased capacity will help bring the European civilian plutonium inventories in balance so that the supply of plutonium from spent reactor fuel will match the demand for plutonium for use in fabricating MOX fuel. It is estimated that MOX fuel demand will match fuel supply capacity after 2005; however, uncertainty about anticipated MOX fuel demand is sufficient that no definite statements about future civilian plutonium

Table A.7. Current and anticipated European MOX fuel fabrication capacity

Owner/facility/location	Current MOX fabrication capacity (MTHM/year)	Anticipated MOX fabrication capacity in 2000 (MTHM/year)
Belgonucleaire/P0/Dessel	35	35
COGEMA/MELOX/Cadarache	30	30
COGEMA/MELOX/Marcoule	80	210
COGEMA/MELOX/La Hague	0	50
BNFL/MDF/Sellafield	8	8
BNFL/SMP/Sellafield	0	120
TOTALS	153	453

balance in Europe can be made at this time. Given this fact and the fact that all of the reactors being considered for the disposition of plutonium could operate on European MOX fuel, two conditions are clear:

- Excess MOX fuel fabrication capacity will persist in Europe until at least 2005. This excess capacity could be used by the FMDP plutonium disposition mission.
- Sufficient MOX fuel fabrication capacity cannot be assumed to be available to ensure completion of the U.S. plutonium disposition program. Therefore, the need for a domestic MOX fuel fabrication facility is required to ensure completion of the plutonium disposition mission.

Appendix B
Schedule Analysis Approach

B.1 Introduction

The National Academy of Sciences (NAS) labeled the existing international regime for surplus plutonium to be a "clear and present danger" and urged that actions be initiated to effect the disposition of surplus plutonium without delay. Thus, timeliness should be a primary determinant for the selection of approaches for plutonium disposition. The FMDP RxAT interprets timeliness to comprise three performance attributes:

- **Time to start disposition:** For the partially complete and evolutionary reactor options, the mission begins when the first reactor begins operating at full power using a full MOX core. For the existing LWR options, the mission begins when the first reactor is loaded with MOX fuel, after the lead use assemblies (LUAs). For the CANDU options, the mission begins when the first reactors are loaded with MOX fuel.

- **Time to complete:** For all of the reactor options, the mission is complete after the final load of MOX fuel has been irradiated for a specified time in the reactor. For the existing and partially complete LWR options, the mission is complete after the first irradiation cycle of the last core load containing MOX fuel assemblies. For the CANDU options, the mission is complete after the final reference MOX or CANFLEX fuel bundles have been discharged from the reactors. In the evolutionary LWR case, the ABB-CE System 80+ loading schedule assumes a single irradiation cycle for each core load with three reshuffles of the core load. The mission is complete after the first reshuffle of the last core load that contains MOX fuel assemblies.

- **Schedule certainty:** A full uncertainty analysis of the implementation schedules was considered premature for the analysis presented in this document. A qualitative assessment of the schedule certainty has been included in the facility schedule sections in Chap. 2.

The schedule estimates were generated by the RxAT presuming a moderate national priority for plutonium disposition, as opposed to the very high national priority associated with the Manhattan Project or the Apollo Project. Similarly, the team assumed no protracted delays with funding, licensing, or technical problems.

B.2 Schedule Elements

Each deployment schedule has been developed by combining the schedules for each of the individual facilities involved in the alternative. The major elements for each of these schedules include:

- project definition and approval;
- siting, licensing, and permitting;
- research, development, and demonstration;
- design;
- facility modification or construction, procurement and preoperational activities;
- operation; and
- decontamination and decommissioning.

The completion of each of these facility elements must be sequenced properly with the other facilities. For example, the MOX fuel fabrication facility needs to have a sufficient supply of PuO_2 to operate. Similarly, the reactors require a sufficient supply of fuel to meet the reload schedule.

In defining the schedule elements for a large government project, a number of activities required for federal projects may not apply or are less important for a private sector project. These complications are reflected in the schedules and include the following elements:

- congressional line item approval and funding authorization,
- compliance with the NEPA, and
- special procurement and vendor selection rules and regulations.

B.3 Schedule Assumptions and Bases

- Some research and demonstration projects are currently under way.
- The project officially starts with the issuance of the programmatic ROD. After ROD, the following tasks begin:
  - — line item funding approval process,
  - — conceptual design of the PuP and MOX fuel fabrication facilities, and
  - — DNFSB review of the use of existing DOE facilities.
- The line item funding approval process has been assumed to take 3 years and to proceed in two phases. After completion of the first phase and intermediate line item funding approval, several activities begin: contract negotiations with M&O contractors, vendors, and utilities; site selection for the new reactors; and Title I design work. After completion of the second phase and final approval of line item funding, Title II design work begins.
- The facility licensing assumptions are as follows:
  - — For the PuP facility, a 5-year oversight review period by the DNFSB is assumed.
  - — For the MOX fuel fabrication facility, a 5-year licensing duration is used. This duration is based on analysis by Fluor Daniel, Inc., with the full discovery period and hearing process durations shortened after further discussions with the NRC.
  - — For all of the LWR facilities, the licensing processes are based on analyses by Fluor Daniels, Inc. For the existing LWRs, the license modification process is assumed to take 4.25 years for the PWR options that do not have integral neutron absorbers in the MOX fuel assembly and to require 5.25 years for the existing BWR option that includes integral neutron absorbers in the MOX fuel assembly. For all of the existing LWR options, the initial reload permit for MOX fuel is not granted until after the LUAs have been irradiated for two cycles. This two-cycle period allows a full irradiation cycle for confirmatory testing of the new fuel design from a new fuel fabrication facility prior to the reload permit review.
  - — For the CANDU HWR facility, the licensing process is based on analyses by AECL and Ontario Hydro and has been estimated to require 4 years.
- Plutonium availability and PuP facility assumptions are as follows:
  - — The schedules assume sufficient plutonium will be available for the fuel development work before the PuP facility is operational.
  - — For all of the options except the Quick Start option (Chap. 5), the production facility operates for 10 years.
  - — For Chapter 5 (the existing PWR option with some MOX fuel fabrication in Europe), the plutonium will be processed in a staged start. This alternative requires PuO_2 feed before the PuP facility could provide it. For this alternative, it is expected that a sufficient quantity of PuO_2 will be available from the ARIES prototype, which is being developed to demonstrate the ARIES process and for design support for the production facility. Using the prototype ARIES line to process some of the mission material also shortens the operational duration of the production facility to 9.1 years.
- The MOX fuel fabrication facility assumptions are as follows:
  - — For most of the reactor options, the MOX fuel fabrication facility will be located in an existing building on an existing federal site and will be GoCo. The exceptions are as follows. The existing PWR option that has an early start, Quick Start, uses fuel fabricated in Europe before fuel fabricated in the domestic facility is available. The MOX fuel assemblies for the existing BWR option are assumed to be fabricated in a new building on an existing federal site. This new building will also contain the PuP facilities. The last exception is the existing PWR option that assumes a privately owned facility located in a new building on an existing federal site. However the implementation schedule is the same as the federally owned facility for two reasons. First, the time required to select the M&O contractor in the federal option is assumed to be of the same duration as selecting the private owner for the facility. Second, the construction time for modifying an existing facility is assumed

to be the same as building a new facility on an existing federal site.

— For the existing LWR options, the initial assemblies will be used as LUAs; full mission fuel production will begin 6 months later.

— The operational schedules for the MOX fuel fabrication facility in each option are based on the fuel assembly production schedule shown in Table B.1.

- The reactor facility assumption is the following:
  — The assumptions for the design, construction and operation of the various reactor facilities are discussed in their respective volumes.
- The HLW repository facility assumptions are as follows:
  — For the LWR options, it has been assumed that the licensing for the HLW repository facility will begin in March 2002 and be completed in August 2010. The construction of the facility will begin in March 2005 and be completed in 2010. The facility will be ready to accept the spent MOX fuel assemblies after the assemblies have cooled in the spent fuel cooling pool for 10 years.
  — For the two CANDU options, it has been assumed that the Canadian HLW repository facility will be opened in 2025. Spent MOX and CANFLEX fuel bundles, which have cooled in the spent fuel pools for 10 years before the opening of the facility, may be stored in dry cask storage until the repository is opened.

Table B.1. MOX fuel fabrication facility production schedule

Alternative	Fuel assembly output/year	Total number of mission assemblies	MOX plant plutonium throughput (MT/year)	MOX plant average throughput (MTHM/year)	MOX plant mission operation (years)
50SFL5, 50SPL5	280	2,756	5	118	9.8
50QSL5 European	85	375	1.5	35.8	4.5
Domestic	280	2,381	5	118	8.5
50COL4	602	9,416	3.2	107	15.6
33SFL3	170	1,819	3.0	71.7	10.7
50SFP2	157	2,692	2.9	69	17.1
50SFE2	129	1,807	3.6	53	14
50SFC2-4	9,050	4,5250	3.0	138	5
	10,500	75,279	5	150	7.2
33SFC2	9,050	98,485	3.0	138	10.9

Appendix C
Cost Analysis Approach

C.1 Introduction

A goal of the FMDP is to minimize the incremental cost impact on the government and taxpayers. Although the national security benefits clearly outweigh the costs involved, significant budget pressures are projected throughout program execution. Timing and allocation of costs were assessed. The following cost-related performance factors were considered to evaluate the extent to which a particular variant is cost-effective.

- **Investment and startup cost**: Investment and startup cost refers to research and development, construction, retrofit, and program infrastructure costs that are incurred early in the program. In government accounting, the sum of these is known as the total project cost (TPC).

- **Discounted life cycle cost**: Discounted life cycle cost (DLCC) is defined as the net present value of all "cradle to grave" government cash flows including those in the TPC. DLCC includes adjustments for revenues that may be produced by electric power production but does not include the sunk (pre-FY 1997) costs of existing facilities or other costs that would be incurred whether or not any action is taken.

For large government projects, such as the FMDP, there is the need to consider not only the costs to design and construct the project but also the costs to operate the facilities over their lives and safely D&D them. For this reason the total life cycle costing (TLCC) approach is used for cost estimating to obtain the true "cradle to grave" costs. This costing methodology also makes comparison of competing plutonium-disposition alternatives more meaningful. Many of the alternatives being considered have different operating lifetimes, and the TLCC concept allows schedule differences to be correctly reflected in overall costs.

Early in the FMDP evaluation process, a set of cost estimating guidelines and a 24-life-cycle category estimating format (Table C.1) were supplied to the alternative teams for each technology. This was done to ensure comparability between estimates and assist the decision-making process. The alternative teams were responsible for preparation of the LCCs, which were then reviewed by the Systems Analysis Team for completeness and adherence to the guidelines. In the case of the reactor estimates, much of the cost data came from 1993 and 1994 plutonium-disposition feasibility studies by reactor vendors, reactor cost data bases at ORNL, DOE plutonium-handling sites such as SRS, and the two weapons research laboratories [Lawrence Livermore National Laboratory (LLNL) and LANL] and their AE subcontractors. The FMDP multilaboratory Systems Analysis Team had the role of "levelizing" the cost data (i.e., ensuring their comparability). It should be noted that the focus in these studies is the LCC to the federal government, and specifically those costs that will be borne by FMDP. Costs to private concerns such as utilities, fuel suppliers, etc., are not considered in this study; however, they may have been used during the estimating process to calculate costs that are ultimately passed on to the federal government. (An example would be the cost of MOX fuel from a privately owned facility specifically built to meet government plutonium-disposition needs.)

C.2 Major Cost Categories

The 24 LCC categories can be rolled into three higher-level categories: investment cost, recurring costs, and D&D costs. Each category includes the following items:

- **Investment or TPC**: This cost is essentially the sum of the "up-front" costs needed to bring a facility into full-capacity operation and includes planning, research and development, ES&H studies (including NEPA), site qualification, quality assurance planning, permitting, licensing, safety analysis, design, construction, project management, initial spare equipment items, facility startup, staff training, and manual preparation.

- **Recurring Costs**: These costs are incurred during normal facility operation after startup and include plant staffing cost (including fringe benefits and taxes), costs of process consumables and

Table C.1. LCC estimate 24-category format

Category	Cost category description
	Preoperational or OPC up-front costs:
1	R&D
2	NEPA, licensing, permitting
3	Conceptual design
4	Implementation plans: QA, site qualification, S&S
5	Postconstruction startup
6	Risk contingency
	TOTAL OF CATEGORIES 1–6 (OPC)
	Capital or TEC up-front costs:
7	Title I, II, III engineering, design, and inspection
8a	Capital equipment
8b	Direct and indirect construction/modification
9	Construction management
10	Initial spares (technology dependent)
11	AFI (percentage of categories 7–10)
12	Risk contingency
	TOTAL OF CATEGORIES 7–12 (TEC)
	TOTAL INVESTMENT OR UP-FRONT COST (TPC = OPC + TEC)
	Other LCCs:
13	O&M staffing
14	Consumables including utilities
15	Major capital replacements or upgrades
16	Waste handling and disposal
17	Oversight
18	M&O contractor fees (2% of categories 13–16 for PuP and MOX facilities)
19	PILT to local governments (1% of categories 13–16 for PuP and MOX facilities)
	TOTAL RECURRING COSTS (SUM OF CATEGORIES 13–19)
20	D&D
21	Revenues (if applicable)
22a	Revenue from sale of reactor
22b	Fees to privately owned facility
23	Transportation of plutonium forms to facility
24	Storage of plutonium at existing 94-1 site facility
	TOTAL OTHER LCC (SUM OF CATEGORIES 13–24)
	GRAND TOTAL ALL LCC (SUM OF TPC + OTHER LCC IN 1996 $M)

maintenance materials, utility costs, administrative and plant overheads, transportation costs for nuclear materials, oversight costs, fees to the facility management contractor, capital replacement items, waste-handling costs, and payments-in-lieu-of-taxes to local communities. [In many of the charts this category falls under "O&M (Operations and Maintenance) and Other LCCs."]

- **D&D Costs**: These are the costs incurred at facility end-of-life to decontaminate and remove process equipment and to decontaminate any process buildings to a safe or "habitable" state where no adverse human health or environmental consequences result from their continued existence on the site.

A special category is that of revenues. For some reactor alternatives the federal government may benefit from the sale of the following items:

— Electricity: If the government owns the nuclear power plant, electricity will be sold.

— MOX fuel: If the government owns the MOX fuel and sells it to a private utility reactor owner, the fuel would probably be sold at a price close to that of an energy-equivalent amount of uranium fuel.

— Reactor power plant: If the government owns the power plant during the duration of the plutonium disposition campaign, it may wish to sell the plant to a utility at the end of the campaign, thus removing the government/FMDP from the business of selling electricity.

C.3 General Cost Assumptions for the Existing LWR and LWR Hybrid Reactor Cases

- All costs are reported in constant 1996 dollars.
- For the existing LWR base case, LCCs are reported for three facilities:
  - — the PuP facility: a federally owned facility assumed located in an existing facility SRS;
  - — the MOX fabrication facility: a federally owned facility assumed located in an existing building at a DOE site with plutonium-handling infrastructure; and
  - — the three to five existing LWRs: utility-owned power plants assumed located in the midwestern United States (for transportation cost estimating).
- For the collocated PuP/MOX variant (Chap. 4), the first two assumptions are modified so that the PuP facility and MOX facility are located within the same PIDAS fence.
- For the hybrid case (assuming an immobilization option is chosen for the 17.5 MT of plutonium), two additional facilities are needed: the vitrification facility located in the existing facility at SRS, and the U.S. repository to handle the glass logs produced. Only the MOX and reactor facility parts of the hybrid alternative are evaluated in this report.
- Plutonium-processing LCCs and MOX fuel fabrication LCCs are based mainly on data from LLNL, LANL, and SRS. Reactor LCCs are based on data from Westinghouse, GE, and ORNL.
- Total discounted dollar cost is calculated by spreading the constant-dollar cash flows in a manner consistent with the project schedule, and then discounting these cash flows at 5% real discount rate as prescribed by the Office of Management and Budget. This discount rate is consistent with the federal government's costs of borrowing.
- Government-owned facilities are assumed to be operated and managed by private corporations or utilities on a fee basis. The contractors' annual fee for the plutonium processing and the MOX fuel fabrication facility is calculated as 2% of the annual recurring costs. The LWR reactor operator receives a fee of $25M per reactor pair per year for the first 5 years, followed by $10M per reactor pair per year thereafter (reflecting decreasing financial risk after five successful years). This is consistent with the assumptions made for other reactor options. This business-negotiable cost category is not included in the cost estimates appearing in Table 4-1 of the TSR. The number of years that the fee is paid is based on the irradiation mission time (i.e., time from the first MOX fuel loaded into a reactor until the last MOX fuel reload is put into the reactor), which approximates the number of equivalent "full-MOX" years that the reactors would operate if there were no gradual ramp-ups or ramp-downs in the reactor loading schedules.
- Comparison with cost information in the *Technical Summary Report (TSR) for Surplus Weapons-Usable Plutonium Disposition:* In the TSR, costs or benefits for negotiable or business-related cost categories were assumed to be zero. In this report, however, these categories are costed; a table comparing the TSR LWR cases and the RASR LWR cases is presented in Appendix H. For the existing LWR variants, the one category so treated is the following:
  - — The incentive fee to a utility for MOX operations in a private facility.
- Reactor staffing costs are based on the "first load in" to "last load out" time period. As long as there is MOX fuel in the reactors, incremental staff will be needed.

Appendix D
Safeguards and Security Analysis Approach

D.1 Introduction

S&S concerns are of two basic types. The first concern has to do with the potential for theft and diversion of materials by disgruntled employees, "unauthorized" groups such as terrorist and subnational organizations, and aspiring nuclear states. The second concern has to do with the threat that the "host" nation (presumably the United States or the Russian Federation) might retrieve the dispositioned plutonium form, extract the plutonium, and reuse the material for weapons production. The performance of the existing reactor-based option in these critical areas has been evaluated and is discussed in this appendix.

D.2 Resistance to Theft or Diversion by Unauthorized Parties

Evaluation Criteria—This metric was developed to address the risk of theft of weapons-usable nuclear material primarily during transportation, storage, and processing, as well as the risk of theft after disposition is completed. The threat was presumed to be theft by terrorists, subnational groups, or aspiring nuclear states, in addition to potential theft by disgruntled employees. This threat can be reduced by minimizing the handling and processing of the material and applying effective S&S measures. Important characteristics included the inherent attractiveness of the weapons-usable material, the number of transportation steps and sites involved, and the number and characteristics of the processing steps that influence the effectiveness of standard S&S practices. The transportation, storage, and processing of the material must meet the Stored Weapons Standard[1] and the condition after disposition must meet or exceed the proliferation resistance of the SFS.[2] Factors considered when applying this criterion were the following:

- **Low inherent attractiveness**: This factor favored alternatives that minimize the attractiveness of the physical, chemical, or isotopic makeup of the nuclear material during processing, transportation, or storage. The risk of theft (or weapons use) is reduced if material is available only in small quantities and/or is in a physical and chemical form that makes recovery difficult.

- **Minimization of transportation and number of sites**: The more complex the logistics, the more opportunities there are for theft. Disposition scenarios that involve very complex logistics with many transfers and storage locations, with attendant transportation requirements, were considered to be more vulnerable to theft.

- **S&S assurance**: The effectiveness of the S&S protection depends on the form of the fissile material and the characteristics of the processes and facilities involved in the storage and disposition activities.

Applicable S&S Requirements and Measures—The S&S requirements for this alternative are primarily driven by the attractiveness of the material as defined in DOE Order 5633.3B (Table 2.12) and/or 10 CFR Parts 73 and 74. Every facility in this alternative (e.g., PuP, MOX fuel fabrication, and reactors) except the repository will be a Category I facility. Information about the flow of plutonium through this alternative and a description of the material and its attractiveness level are provided in Chap. 2. The DOE attractiveness levels are defined in Table 2.12.

A number of different forms are received by the PuP facility (IB to IID). This material is converted into PuO_2 (IC), which is sent to the MOX fuel fabrication facility. At the MOX fuel fabrication facility the PuO_2

[1] The Stored Weapons Standard was selected by NAS to mean that, to the extent possible, the high standards of security and accounting applied to the storage of intact nuclear weapons should be maintained for these materials throughout dismantlement, storage, and disposition.

[2] The SFS was defined by NAS to mean that alternatives for the disposition of plutonium should seek to make this plutonium as inaccessible or unattractive for weapons use as the much larger and growing stock of plutonium in civilian spent fuel.

is made into fuel, but the attractiveness level (IC) remains the same. A single fuel assembly contains more than 6 kg of plutonium and therefore meets the criteria for Category I. The presence of fresh MOX fuel is the primary factor that will affect S&S areas for the reactor facilities. Once the MOX fuel has been irradiated, the S&S requirements/procedures should not be significantly different from what is currently required at existing reactors.

Highly irradiated MOX fuel (e.g., a radiation dose rate in excess of 100 rem/h at a distance of 3 ft) will be considered as Category IVE and will be exempt from certain requirements in 10 CFR 73 for SNM (10 CFR 73.6). If after a period of time, the irradiated MOX fuel no longer meets the above radiation dose criteria, then it may be considered as Category IID, depending on the quantity of SNM present. Protection against radiological sabotage should likewise not be significantly different for MOX fuel. In order to meet the requirements for protection of the more attractive fresh MOX fuel, it may be necessary for reactors to upgrade their facilities, procedures, and personnel qualifications.

Category I and/or strategic SNM must be used or processed within an MAA. Material that falls under attractiveness levels IB to IC must be stored, at a minimum, in a vault-type room. To protect against radiological sabotage, reactors have both a protected area and vital area but would not normally have an MAA or equivalent protection. The requirement for an MAA and vault-type storage room means that certain physical protection enhancements may be required beyond what currently is present at existing reactors (e.g., beyond 10 CFR 73.55). At least three barriers must protect strategic SNM with the physical barriers at the protected area consisting of two barriers with an intrusion detection system placed between them. The protected area boundary must also provide for a barrier from vehicle penetration. The access control points into the protected area must be made of a bullet-resistant material. Duress alarms will be necessary at all manned access points. There will be enhanced entrance/exit inspections of personnel, vehicles, and hand-carried items. MAA/protected area portals will typically have metal detectors, SNM detectors, and perhaps X-ray machines for hand-carried items. If Category I SNM is to be stored, the storage area must meet the criteria of a vault-type room, which means an area with enhanced barriers, access control, and motion sensors to detect penetration.

Possible Diversion, Theft, or Proliferation Risks—This criterion evaluates the system resistance to theft by an outsider and/or an insider and retrieval after final disposition by outside groups. Theft or diversion of material refers to both overt and covert actions to remove material from the facility. This is perpetrated by unauthorized parties including terrorists, subnational groups, criminals, and disgruntled employees. Protection of the material and information from these parties is a domestic responsibility, not an international one. It is internationally recognized that protection against these threats is a state's right and obligation. For this criterion the primary concern is that of theft of fissile material by a subnational group. There are a number of possible adversary groups with different motivations and capabilities. The actions could be overt such as a direct attack on a facility, or they could involve covert measures that might utilize stealth and deception as well as possible help from an "insider." It is assumed that all facilities will meet the necessary S&S requirements and that existing measures will help mitigate any risks. Still, the threats to facilities will be different, depending on the form of the material, the activities at the facility, and the barriers to theft (both intrinsic to the material and also to the facility).

Criterion Measures—The measures identified for this criterion are the environment, material form or characteristics, and S&S. These measures are briefly described below, and a qualitative discussion of the relative risks is presented for each of the facilities in this alternative for these measures. Tables 2.11, 2.23, and 2.37 provide specific information derived from the RxAT data calls and other sources concerning these measures for the various facilities within this alternative and provide most of the information needed to evaluate the above measures. Table 7.3 summarizes the potential risks. This analysis is qualitative based on available data and will be refined later in the decision process.

- **Environmental Conditions**: The logistics, physical location, throughput, inventory, and the state during processing, transportation, or storage affect the opportunities for theft. The more complex the operations (e.g., large operations, number of steps, transfers, or processes), the more opportunities there are for theft. The more inaccessible the physical location (e.g., storage locations), the fewer the opportunities for theft. Throughput is particularly important for operations involving bulk operations. When the material is in discrete items, this factor is less important. For transport

operations the number of trips and distances traveled (particularly for off-site moves involving SSTs) are important.

- **Material Form**: Attractiveness is based on physical, chemical, or nuclear (isotopic and radiological) makeup of the nuclear material during processing, transportation, or storage. The risk of theft for weapons use is reduced if material is available only in small quantities, is in a physical and chemical form or matrix that makes recovery difficult, or is isotopically unattractive. The DOE attractiveness table found in DOE Order 5633.3B is the primary basis for evaluating the material form. The presence of other fissile nuclear material, particularly in a separated form, will affect opportunities for possible diversion of plutonium.

- **S&S Assurance**: The effectiveness of S&S protection depends on the form of the material, the physical protection characteristics of the processes, facilities involved in the storage and disposition activities, and the material measurement systems being applied.

Ability to Achieve the SFS—The "SFS" means that the material is comparable to existing spent fuel at commercial reactors with respect to its environment, material form, and S&S. The plutonium in MOX spent fuel is as difficult to divert or steal as plutonium in commercial spent fuel. In fact, since the origin of the MOX fuel is from weapons material, there is a good chance that this material may have increased visibility with respect to safeguards. *The final disposition form for this alternative meets the SFS.* Both significant extrinsic (facility) and intrinsic (related to the material form) safeguards exist. Since the radiological barrier is time dependent, this attribute will, over a long period of time, decrease, and the material will not be self-protecting. Before the irradiation of the fuel assemblies, the material does not meet the SFS, and therefore, protection commensurate with its attractiveness level must be provided.

S&S Transportation-Related Issues—Transportation of SNM such as plutonium exposes the materials to threats of theft and diversion outside the controlled areas of secured nuclear facilities. These threats are addressed by DOE and the NRC through implementation of requirements for administrative controls on transportation planning, preparations, activities, and oversight, and through the use of advanced technologies for payload security and shipment monitoring. NRC established regulations in 10 CFR, Sect. 73.37, requiring implementation of measures to ensure that shipments of SNM are secured from theft and diversion during transport. The measures include provisions for specially equipped transportation vehicles that become immobile if subjected to a diversion threat; frequent and planned communications between an in-transit shipment and the shipper facility; location monitoring and reporting of shipments on an every 2-h basis; armed escorts; security-cleared vehicle operators and escorts; and route planning approved in advance by the NRC.

Safeguarding and security for DOE shipments of weapons-usable materials, such as plutonium, are governed by DOE Order 5632.2B. This order specifies the levels of security that are required for varying quantities and types of materials that are shipped. SST vehicles are to be used for the shipment of all materials classified as Category I materials (weapons assemblies, pure products, and high-grade materials). Category II materials, which are all materials that could be used with little technological effort to produce a nuclear weapon (weapons-usable materials), are also required to be transported in SSTs unless these materials have been provided with diversion resistance. Plutonium materials associated with the RxAT alternatives, except SNF, are believed to all fall into the Category I or II classifications, thus requiring SST level of transportation security. The technical features of the SST system are necessarily classified to protect its effectiveness in preventing theft or diversion of materials that are shipped. In general, however, SSTs provide an extremely resistant barrier to intrusion into the vehicle's closed cargo area where packages of plutonium materials will be carried. Minimizing the number and/or duration of the transport steps is desirable.

D.3 Resistance to Retrieval, Extraction, and Reuse by the Host Nation (Applies to Disposition Only)

Evaluation Criteria—One goal of the program is to make it unlikely that the surplus weapons-usable materials could be reused in weapons. High resistance to retrieval would provide other nations with the confidence that a relatively large resource expenditure (cost and time) would be required to reconstruct the stockpile from dispositioned material. Barriers to reuse result from the form of the material, physical location of the material, and institutional controls (such as IAEA safeguards). A goal of disposition is to reduce reliance on institutional controls.

Modification of the weapons-usable material to make it as difficult to use for weapons production as plutonium contained in spent commercial reactor fuel would make the proliferation and rearmament threat associated with the surplus weapons-usable materials no greater than the threat resulting from plutonium in spent fuel. When modified, the surplus weapons-usable materials would not require a unique level of domestic and international safeguards.

From the perspective of this criterion, it might seem better to make the weapons-usable material as difficult to use as mining and enriching natural uranium. However, the greater degree of proliferation resistance provided by technologies that go beyond the SFS was not considered to be worth the additional time and cost required, especially in light of the significant quantities of plutonium that exist in spent fuel.

For the specific issues to be addressed in ongoing evaluations, the "host nation" is the United States for most of the alternatives considered. However, the motivation for taking these actions is driven by concerns about Russian safeguards. The degree to which U.S. actions would foster progress and cooperation with Russia to provide effective storage and disposition of their materials is addressed in the screening criteria for the FMDP.

The following factors were considered when these criteria were applied:

- **Difficulty of retrieval, extraction, and reuse**: This factor addresses the difficulty (reflected by cost and time) of retrieval of surplus weapons-usable material and its reuse in weapons, and

- **Assurance of detection of retrieval and extraction**: This factor primarily deals with how difficult the material would be to retrieve and extract in a clandestine manner, which depends on the resultant material location and form.

Applicable Safeguards Requirements and Measures—The safeguards requirements for this alternative are based on INFCIRC 288, 66, 153 and the IAEA safeguards inspection criteria 1990-11-21. These evaluation criteria measure the system resistance to diversion of material and conversion of the material back into usable form by a weapons state, both before and after final material disposition. This refers to covert attempts to remove material from the system by the host nation or state. Again the material form, environment, and safeguards are particularly important for detecting the diversion, retrieval, and extraction activities. In addition, the irreversibility of the material form is important for assessing its reuse in nuclear devices. Nuclear material for this alternative falls under the IAEA categories DUU (e.g., plutonium metal and compounds, MOX powder and pellets, MOX fuel rods and assemblies) and DUI (e.g., MOX fuel in the reactor core, spent MOX fuel). Some of the other fissile material in the FMDP is not considered by the IAEA.

The only existing worldwide inspection regime that exists to address this threat is the IAEA. One mission of the IAEA is timely detection of the diversion of nuclear material from declared nuclear activities. An important measure used by the IAEA is the "significant quantity" measure, which for plutonium is 8 kg. Since the state owns and operates the physical protection and material control and accountancy measures, the IAEA does not rely on these systems to fulfill their obligations. The IAEA does independent verification of the data from the state's system of material control and accountancy. The IAEA, in performing its safeguards inspection activities, audits the facility records and makes independent measurements of selected samples of each kind of nuclear material in the facility. To help the agency fulfill its responsibilities, this verification is coupled with a technology known as "Containment and Surveillance (C/S)," which is designed to provide "continuity of knowledge" during inspector absence. Much of the C/S equipment used by the IAEA is very similar in technology and in some cases nearly identical to the seals and surveillance equipment used by national authorities in physical protection functions. Although the technologies may be the same, the objectives are different. For example, for domestic requirements optical surveillance is generally monitored in or near real time by security forces, whereas for the IAEA to the unattended surveillance monitors activities over a 1–3 month period.

The philosophies and implementation of international safeguards (commonly referred to as IAEA safeguards) are substantially different from domestic S&S (as DOE and NRC practice). These activities will quite likely require additional accountability verification (e.g., identification, weighing, sampling and analysis, and NDA, as well as increased inventories and item checks), C/S measures installed throughout the facilities (e.g., surveillance, seals, monitors, tags); space for inspectors; and equipment for independent measurements by international inspectors. In addition, classified information will need to be protected

beyond what might currently be necessary. This is an issue for the PuP facility, where some of the material input to this facility is pits, and perhaps other classified matter that under current laws cannot be divulged to IAEA inspectors (e.g., disclosure of weapons design information violates the Atomic Energy Act and the 1978 Nuclear Nonproliferation Act). So, at least part of this facility will not be under international safeguards, and therefore, verification by the IAEA is not possible until agreements between the IAEA and the United States can be accomplished. A number of different options that address this problem are being considered. They include processing weapons-related components and material and, after the material has been converted into a declassified form, making it available for the IAEA and the use of modified IAEA safeguards until the material is unclassified.

Possible Diversion, Reuse, and Retrieval Risks—As mentioned above, the threat for this criterion is the host nation. Although the host nation may choose to use overt measures to obtain material and/or weapons design information, the greatest concern is with covert attempts. Because the state has responsibility for physical protection and MC&A, the IAEA will seek to independently verify material accounting. C/S complements the material accountability measures. The vulnerability to diversion is dependent on the environment, material form and safeguards measures, and the ability to retrieve and convert the material into a weapons-usable form. Therefore, if we were to evaluate each of the facilities for this alternative, there may be some differences. Because of inherent limitations on the accuracy of NDA measurements, there is increased risk for diversion at high throughput facilities. This is where C/S plays an important role in assuring material accountability. Existing protective measures will help mitigate these risks.

Criterion Measures—Again the measures of the environment, material form, and safeguards and security measures contribute to this criterion. Thus, the information found in Table 2.11 is applicable; however, the capabilities of the adversary (e.g., the host nation) must be considered when this information is analyzed. The primary measures are the irreversibility of the material forms (e.g., the ability to convert the material back into weapons-usable form) and the ability to detect diversion, retrieval, and conversion, which is dependent on material form, the environment, and safeguard measures. The performance measures that would demonstrate effectiveness in this area are in terms of the following:

- **Difficulty of diversion, retrieval, extraction, and reuse**: The difficulty of retrieval of surplus plutonium and its reuse in weapons establishes the timeliness and irreversibility criteria and the level of safeguards required. The material form and location are particularly important measures.
- **Assurance of detection of retrieval and extraction**: The difficulty of detection or diversion of a significant quantity of material depends on material form, environment, safeguards, and the following factors:
  - — ability to measure material, which includes processing that is under way, accuracy of applicable NDA techniques, the presence of waste streams, classification issues that may prohibit measurement, and whether item accountancy instead of bulk accountancy methods can be applied;
  - — C/S systems; and
  - — timeliness of detection.

Ability to Achieve the SFS—The final disposition form for this alternative meets the SFS. Both significant extrinsic (facility) and intrinsic (related to the material form) safeguards exist. Since the radiological barrier is time dependent, this attribute will, over a long period of time, decrease, and the material will not be self-protecting. Before the irradiation of the fuel assemblies, the material does not meet the SFS, and therefore, protection commensurate with its attractiveness level must be provided.

S&S Transportation-Related Issues—For all Category I material, SSTs will be used to move the material between facilities. A secure unloading area must be available to receive and verify the material and send it to the storage area. Only after the MOX fuel has been irradiated will the requirement for SST movement be removed. IAEA safeguards can be applied for SST transportation of plutonium materials. Tamper-indicating devices/seals can be applied to packages containing excess plutonium materials, and the cargo compartments of SST vehicles provides an extremely resistant security barrier. Use of welding to attach seals to an SST would not be permitted because it would compromise security. Inspection of SST loading and unloading that does not require access to design features of the vehicle would also be permitted. Since the characteristics of the SST design must be protected to ensure its mission effectiveness, inspections that use instruments (in particular, equipment that uses radiative power) would be prohibited.

However, inspections of tamper-indicating devices/seals and other approved international safeguards devices would be permitted. Monitoring of SST payloads would also be permitted under the condition that such monitoring would not compromise security through tracking of a vehicle's geographic location. Shipment route data and other sensitive data that must be classified to protect the secure operations of SSTs would not be available for IAEA inspection. Inventorying of payloads before shipment and following receipt would be allowed except under conditions that the excess fissile material contains restricted data.

Appendix E
Quantitative Technical Viability Assessment

E.1 Technical Viability Assessment Scale

An early plutonium disposition study by Omberg[1] contains a proposal for a technical readiness scale. For the purpose of the current application, this scale is deficient in four areas: It assumes that scientific feasibility of a concept has been demonstrated. It does not include the final phase of development, which is commercialization. It does not include the possibility that experimental work and analyses may be required in order to satisfy safety and/or regulatory requirements. It appears to be based on assumptions that there are no time lags between various stages of development; no allowances are made for the loss of corporate memory resulting from schedule delays.

For this study, the scale of Omberg has been modified to include stages related to the demonstration of scientific feasibility. This requires that the process under consideration has been demonstrated in the laboratory, that scientific phenomena have been confirmed, and that all principles governing the behavior of the process are believed to be known.

Another modification made to the original Omberg scale is an addition of two final stages for which completion will designate that the process being considered has been commercialized. These stages are the achievement of "final application in the proper operating environment" noted, but not included, in Omberg.

To account for the requirements imposed by the need for regulatory approvals, a six-level regulatory status scale is postulated in Table E.1. Because the Nuclear Regulatory Commission (NRC) has never licensed a PuP facility or a MOX fuel fabrication facility, phases of the NRC approval are difficult to define precisely. (The regulatory procedure for a geologic repository, although formulated, has never been carried to completion.) For these reasons, the scale shown in Table E.1 is not linked to specific regulatory procedures.

Table E.1. Regulatory assessment scale

Regulatory status level	Definition
1	No contact with a regulatory agency
2	Discussions initiated with a regulatory agency
3	Continuing discussions; experiment/ analyses programs defined
4	Continuing discussions; experiment/ analyses programs under way
5	Continuing discussions; experiment/ analyses programs complete
6	Final approval received from a regulatory agency

In Table E.2, the regulatory status scale has been combined with the modified scale from Omberg to form the reactor alternatives technical viability scale. The maturity level reflects the degree of viability of a process. A value of 1 indicates low viability. A value of 12 reflects the highest degree of viability, that of a currently operating process.

A subtle but an important point is that the scale in Table E.2 is based on the assumption that success is possible. If a process is viable at the laboratory level but could not be developed into a prototypic process (e.g., the process is not scaleable to an industrial level), the process does not remain at a utility value of 4. Instead, the function to be fulfilled by the process or facility must be degraded to a utility value of 1. The scale in Table E.2 is only applicable to processes or facilities for which it is possible to progress up the scale.

An assumption of plausibility with respect to other assessment criteria is necessary for technical viability studies to be conducted independent of other assessment criteria such as safeguards or economics (i.e., to study *technical* viability, *not* overall viability, of a concept. In performing the technology level assessments needed for selecting a utility value from

Table E.2. Technical viability scale

Maturity level	Designation	Regulatory status scale	Comment
1	Conceptual	1	Basic principles of the concept, function, and potential application have been proposed
2	Lab-1	1	Some scientific investigations (calculations and/or experiments) have been conducted
3	Lab-2	1	Scientific investigations (calculations and/or experiments) currently under way
4	Lab-3	1	Scientific feasibility has been demonstrated
5	Prototype-1	1	A basic engineering system has been defined to implement technology principles and determine if the system can perform the function in the specific application of interest
6	Prototype-2	2	Functions critical to the performance of the engineering system have been identified and verified with applicable computer codes or general experimental data
7	Prototype-3	3	Design trade-offs for the engineering system have been identified to establish a reference design configuration. Initial collection of safety-related data is being performed. Existing technologies are available but have not been demonstrated for this application
8	Prototype-4	4	The system design is complete. The technology development process begins transition into a technology demonstration. Continued data gathering is underway to support licensing
9	Prototype-5	4	The technology development process has progressed to integrated system demonstration. Collection of safety-related data is complete. Safety-related analyses are continuing
10	Prototype-6	5	A final design is approved or approval is pending with no outstanding issues of significance. An integrated system has been demonstrated at a scale relevant to the final application in the proper operating environment. Safety-related analyses are complete
11	Commercial-1	6	A facility or process is operational but lacks capacity to perform the mission or has been operational at the desired scale or throughput but is not currently in operation
12	Commercial-2	6	A facility or process is operational and is available

Table E.2, one must assume that there are no impediments to technological development caused by other criteria. This assumption is believed valid because the "screening process" used to select the reactor options is intended to remove any alternatives containing processes likely to be inadequate because of consideration of criteria.

E.2 Derivation of a Technical Viability Index

Each facility in the reactor alternatives is composed of processes, and each process is at some stage of development. These processes are identified previously in this report and are listed in Table E.3. For each

Table E.3. Technical viability rankings for existing reactor alternatives

Process	Weighting function	Maturity level	Reason not lower	Reason not higher
Plutonium processing—shipping to plutonium processing	1.00	11	Pantex is receiving material at the desired rate	There is no surplus facility capacity to do this for the front end
Plutonium processing—receiving	1.00	7	A receiving facility exists at the SRS	A receiving process used previously at Rocky Flats was not adequate. The item accounting that was used did not account for radioactive decay and led to unacceptably large inventory differences. A new receiving process must be specified that will require measurement of all materials received
Plutonium processing—pit and metal processing	2.0 for 50QSL5[a]; 0.65 for other 50-MT options; 1.0 for 33-MT option	6	The technical viability reported is the average for the component process (gas sampling, bisection, plutonium removal, and HEU decontamination). Although some of the subprocesses have been done at Rocky Flats at the desired scale (gas sampling) and can be given a high technical viability rating, other processes are under development	The bisection system has not been specified for all components. Parting bisector and lathe will be tested as a part of the ARIES program to establish final system design. The scientific feasibility of the hydride/dehydride process has been demonstrated during FY 1995. Experiments are under way to optimize operating parameters and system hardware design. HYDOX system has not been demonstrated or proven. Will be tested as a part of ARIES. The baseline Rocky Flats process for oralloy decontamination generates an unacceptable amount of aqueous waste. A new nearly waste-free system has been demonstrated during FY 1994 and FY 1995 and shown to be scientifically feasible. Hydride/dehydride process can also be used to purify metal
Plutonium processing—gallium removal	2.0 for 50QSL5, 0.65 for other 50-MT options, 1.0 for 33-MT option	7	Experiments to determine process parameters are currently being conducted	System design is not complete

Table E.3. Technical viability rankings for existing reactor alternatives (cont.)

Process	Weighting function	Maturity level	Reason not lower	Reason not higher
Plutonium processing—uranium/ UO_2/PuO_2	0.05 for 50-MT option, 0.0 for 33-MT option	5	Hydrochloric acid separation; rating by facility lead	Assessment by facility lead
Plutonium processing—halide salts/oxides processing	0.05 for 50-MT option, 0.0 for 33-MT option	5	Salt distillation laboratory scale only	Assessment by facility lead
Plutonium processing—oxidelike materials processing	0.05 for 50-MT option, 0.0 for 33-MT option	5	Hydrochloric acid dissolution; assessment by facility lead	Assessment by facility lead
Plutonium processing—alloy reactor fuel	0.05 for 50-MT option, 0.0 for 33-MT option	11	Done commercially at INEL; however, there could be difficulties with the plutonium processing that could reduce this to a maturity level of 7	Sufficient capacity not available
Plutonium processing—SS&C, impure metal, and plutonium alloys	0.05 for 50-MT option, 0.0 for 33-MT option	5	Hydrochloric acid dissolution; assessment by facility lead	Assessment by facility lead
Plutonium processing—clean oxide, impure oxide, and oxide reactor fuel	0.10 for 50-MT option, 0.0 for 33-MT option	12	No processing required	N/A
Plutonium processing—shipping	1.00	7	Assessment by facility lead	Assessment by facility lead
Fuel fabrication—plutonium receiving and storage	1.00	9	Facilities for plutonium oxide storage have been built and approved by DOE	A final design has not been generated
Fuel fabrication—nonplutonium receiving and storage	0.20	11	Similar facilities exist and are operating; size or scale not a concern	Facility for this specific purpose is not available
Fuel fabrication—PuO_2 purification	1.00	6	Critical functions have been identified with experimental data	Reference design not fully established

Table E.3. Technical viability rankings for existing reactor alternatives (cont.)

Process	Weighting function	Maturity level	Reason not lower	Reason not higher
Fuel fabrication—feed materials preparation	1.00	4 for 50COL4 --- 7 for all other options	Scientific feasibility of blending burnable poisons and uranium has been demonstrated. Production of nonpoisoned MOX has been demonstrated --- Technology available but not applied; design trade-offs have been done	An engineering system has not been developed. Ordering of the blending steps for uranium, plutonium, and poison are not identified --- System design not complete. Needed safety data identified but data collection not initiated
Fuel fabrication—fuel pellet fabrication	1.00	6 for 50COL4 --- 8 for all other options	Critical functions are known based on uranium performance --- System design believed known	Collection of safety-related data has not been initiated --- Collection of safety-related data is not complete. Irradiation tests may lead to changes in pellet design
Fuel fabrication—fuel rod fabrication	1.00	9	System design (rod materials, diameter, pitch) complete; few or no changes from LEU design expected	Final design has not been approved
Fuel fabrication—fuel bundle assembly	1.00	9 for 50COL4 --- 7 for all other options	Assembly should be the same as for LEU --- Existing technologies (fixed poison rods) are available	Final approval has not been received from regulatory authority --- System design not complete; number and placement of poison pins uncertain
Fuel fabrication—materials recycle	0.50	7	Existing technologies are available, but not all have been applied; reference design envisioned; considerable safety data exist	System design is not complete
Fuel fabrication—waste management	0.50	9	Similar systems have been demonstrated	A final design is not approved; waste content will depend on source plutonium impurities
Fuel fabrication—bundle shipping	0.20	9	Safety-related analyses continuing but not completed	A final design has not been approved
Reactor—fresh MOX storage	1.00	9	Design expected to be similar or the same as for LEU fuel. Safety-related analyses are continuing	A final design is not approved
Reactor—fuel storage pool	1.00	12	Existing facility designed for natural uranium fuel should be applicable for MOX with few or no changes	N/A

Table E.3. Technical viability rankings for existing reactor alternatives (cont.)

Process	Weighting function	Maturity level	Reason not lower	Reason not higher
Reactor—core configuration	9.475 for 50QSL5, 8.125 for other 50-MT options, 8.30 for 33-MT option	8	No changes proposed to existing core configuration	Collection of additional safety-related data believed needed
Reactor—spent fuel storage pool	1.00	12	Existing facility designed for uranium fuel should be applicable for MOX with few or no changes	N/A
Reactor—dry spent fuel storage	1.00	9	Existing MPC design should be adequate	Safety-related analyses not complete
Reactor—shipping	0.200	9	Existing MPC design should be adequate	Safety-related analyses not complete
Repository—surface, security	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface staging area	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface receiving bay	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, handling cells	0.1250	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, welding	0.1250	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, decontamination	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, vault	0.1250	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, transfer area	0.1250	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, cask maintenance	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—surface, waste treatment	0.0625	11	Existing MPC design should be adequate	Sufficient capacity does not exist
Repository—subsurface, emplacement	0.1250	11	Existing MPC design should be adequate	Sufficient capacity does not exist

Table E.3. Technical viability rankings for existing reactor alternatives (cont.)

Process	Weighting function	Maturity level	Reason not lower	Reason not higher
Repository—geologic facility postclosure isolation and safety	8.475 for 50QSL5, 7.125 for other 50-MT options, 7.30 for 33-MT option	8	Transition to technology demonstration is in progress. System design believed complete	Integrated system demonstration not achieved. Collection of safety-related data is not complete
Sum[b]	37.9 for 50QSL5, 33.2 for 33SFL3, 32.5 for other options	348 for 50COL4, 351 for other 50-MT options, 308 for 32.5 MT		
Weighted product		310.15 for 50QSL5, 268.00 for 50COL4, 271 for other 50-MT, 275.6 for 32.5 MT		
Unweighted viability factor[c]		8.92 for 50COL4, 9.0 for other 50-MT, 9.31 for 32.5 MT		
Weighted viability factor[c]		8.18 for 50QSL5, 8.25 for other 50COL4, 8.34 for other 50-MT, 8.30 for 32.5 MT		

[a]Options are defined in Tables A.4 and A.5.

[b]Sum does not include processes that have a weighting function value of zero.

[c]Viability factor = Weighted sum/sum of weights. A value of 12.0 means the alternative is commercialized; a value of one means that the alternative exists "only on paper."

process in each reactor alternative, the degree of technical viability is assessed, based on the categories defined in Table E.2. Each process is evaluated under the assumptions that preceding processes are accomplished successfully (i.e., each process is evaluated independently from all other processes that form the alternative).

An overall figure-of-merit or weighted technical viability factor for each alternative/variant is derived by summing the product of the technical maturity values (defined in Table E.2) and the weighting function values assigned to each of the processes. This sum of the products is then divided by the summation of the weighting function values for all processes. The resulting quotient is the weighted viability factor listed at the end of Table E.3, which is the desired figure of merit. The highest possible figure of merit for an alternative is 12. The lowest possible value is 1.0.

Several of the subjective weighting values listed in Table E.3 differ from unity. Justifications for all nonunity assignments are provided subsequently.

The nonunity plutonium processing weight functions were defined based on the relative quantities of material expected to be received at the processing facility; that is, 65% of the material is expected to be in the

form of metal, 35% in other forms. Only the metal materials will require removal of gallium.

For the hybrid option, only the metal pits will be processed for reactor fuel. The other plutonium-bearing forms will be prepared for immobilization. Consequently, for the hybrid option, the weights for plutonium metal processing and gallium removal were set at 1 and the weights for the other processes in the plutonium processing facility were set at 0 to reflect their absence from the reactor fuel preparation process.

For the Quick Start option, 50QSL5, the weights for the metal processing steps were set at 2.0 to reflect the importance of these steps in the successful accomplishment of the initial, fuel assembly production. The ARIES process *must* produce an acceptable product in order for the Quick Start to be accomplished. The "window" for an acceptable substitute to be found should the ARIES process fail is only 1.5 years. It would be difficult to bring an aqueous process on-line in such a short period of time. For other options, the construction time for the PuP facility ensures that either a faulty ARIES process could be modified or an aqueous process could be substituted for ARIES.

The value of 2 assigned to the metal processing steps of 50QSL5 is somewhat arbitrary. The value must be greater than 1.0 (which is the value for the hybrid option) and less than 7.125 (the value for the repository). Regardless of the value chosen between these two limits, the technical viability index for the Quick Start option will always be lower than that for the other, nonintegral burnable absorber options. It is this conclusion, rather than the precise quantitative value that is significant.

The fuel fabrication nonplutonium receiving and storage functions were judged to be equivalent in difficulty of design to these functions for existing facilities and were assigned a weight of 0.20. The fuel fabrication materials recycle and waste management processes were judged less important than the other fabrication processes because problems or delays in performing these functions could occur without necessarily interrupting the fabrication of MOX fuel. The assignment of 0.5 reflects that these are lesser but still important functions. Shipping of fresh fuel to the reactor and spent fuel from the reactor were judged to be relatively simple items to commercialize and were assigned a weight of 0.2.

The reactor core configuration was assigned a large weight (25% of the sum of all weights) because it is *the fundamental process* by which the weapons-grade plutonium characteristics are modified to be similar to spent fuel from commercial reactors. All other reactor processes were assigned lower weights because of a judgment that the qualification of the balance-of-plant was considerably easier to accomplish than the core design.

The weights for all surface repository processes were set such that their sum would equal 1 because of the simplicity of these operations as compared with other processes in the alternative. Certain surface functions were judged by the facility manager to be simpler operations than others, and their weights were reduced accordingly. The repository cask maintenance and waste treatment process values were reduced relative to other surface processes because problems or delays in performing these functions could occur without necessarily interrupting the storage of spent fuel. The subsurface portion of the repository was assigned a large weight (25% of the sum of all weights less the sum of the repository surface processes) because recovery from failure of this process would be more difficult than recovery from the failure of other processes.

Though not considered in the current work, a different weighting for the subsurface portion of the repository would be required for other plutonium disposition options (immobilization or storage in a borehole) being studied by DOE. Whereas the reactor core design process achieves the goal of transforming weapons-grade plutonium for the reactor options, plutonium/fission product vitrification and subsurface storage are the principal processes for achieving the disposition goal for the immobilization and borehole options, respectively.

E.3 Reference

1. R. P. Omberg and C. E. Walter, *Disposition of Plutonium from Dismantled Nuclear Weapons: Fission Options and Comparison*, LLNL, UCRL-ID-113055 (February 1993).

Appendix F
Description of Plutonium Feed Materials

The surplus weapons-usable plutonium is currently stored at multiple sites across the DOE complex, as shown in Fig. F.1. The Department of Energy is working on a PEIS to make long-term storage and disposition policy decisions for excess plutonium. Although long-term disposition of plutonium is not expected to start for 10 to 15 years, DOE is actively implementing recommendations of the DNFSB (DNFSB Recommendation 94-1) involving immediate and near-term stabilization and repackaging of plutonium at a number of DOE facilities. Table F.1 shows a breakdown of plutonium inventories (by site and form) that are excess to national security needs. Figure F.2 shows a graphical representation of the breakdown of (1) weapons-grade and (2) reactor- and fuel-grade plutonium by form. Storage options under consideration include (1) upgrading all current plutonium storage facilities, (2) consolidating all excess plutonium at a single location, and (3) consolidating excess plutonium at multiple storage locations (while closing some current locations).

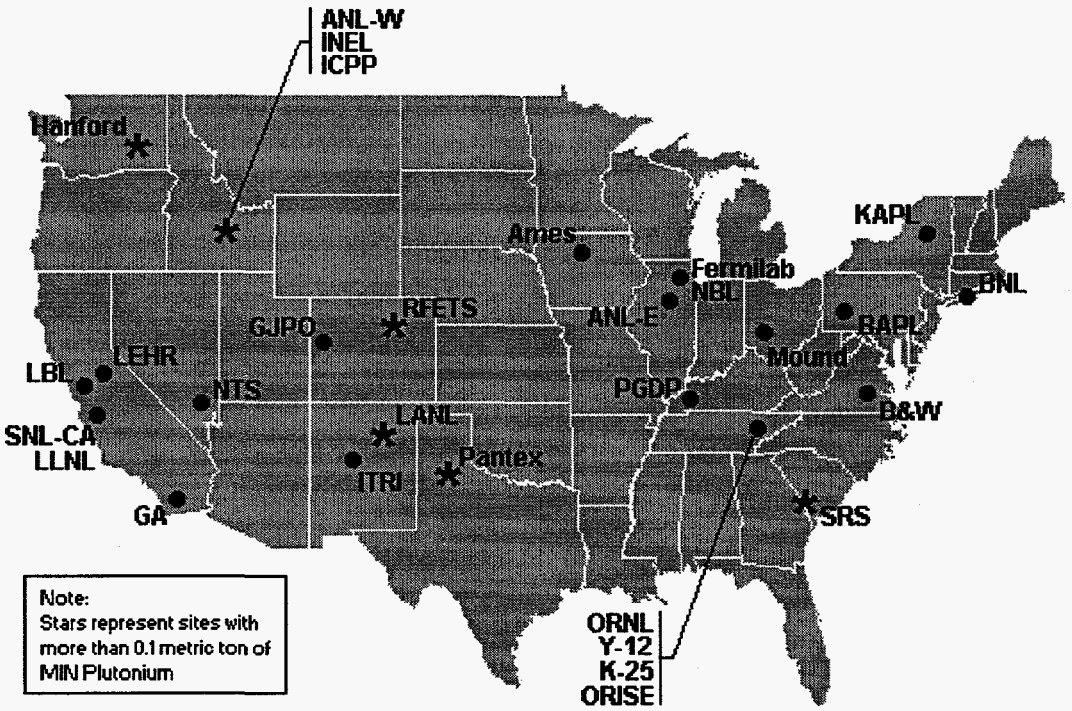


Figure F.1. Geographic distribution of DOE sites storing surplus plutonium. *Source*: DOE, *Taking Stock: A Look at the Opportunities and Challenges Posed by Inventories from the Cold War Era*, DOE/EM-0275, January 1996

Table F.1. Plutonium inventories in excess of national security needs[a,b] by site and form

Site	Weapons grade						Reactor and fuel grades			Total plutonium inventory
	Metal	Oxide	Unirradiated fuel	SNF	Other	Total	Separated (all forms)	SNF	Total	
Pantex plus planned dismantlements	21.3					21.3				21.3
Rocky Flats	5.7	1.6			4.6	11.9				11.9
Hanford Site (PNL and Hanford)	<0.1	1		0.2	0.5	1.7	2.9	6.4	9.3	11
LANL	0.5	<0.1	<0.1		1	1.5	0.3		0.3	1.8
SRS	0.4	0.5		0.2	0.2	1.3	0.4	0.1	0.5	1.8
INEL (INEL, ICPP, and ANL-W)	<0.1		0.2	0.2	<0.1	0.4	3.6	0.4	4	4.4
Other sites	<0.1			<0.1	<0.1	0.1	0.2		0.2	0.3
Totals	27.8	3.1	0.2	0.6	6.4	38.2	7.5	6.9	14.4	52.6

[a]Includes plutonium in SNF and small amounts of plutonium that are in use in non-national security programs.
[b]Totals may not add because of rounding. Amounts reported in metric tons.
Source: (1) DOE Openness Initiative, February 6, 1996, p. 88; and (2) DOE, *Taking Stock: A Look at the Opportunities and Challenges Posed by Inventories from the Cold War Era*, DOE/EM-0275, January 1996.

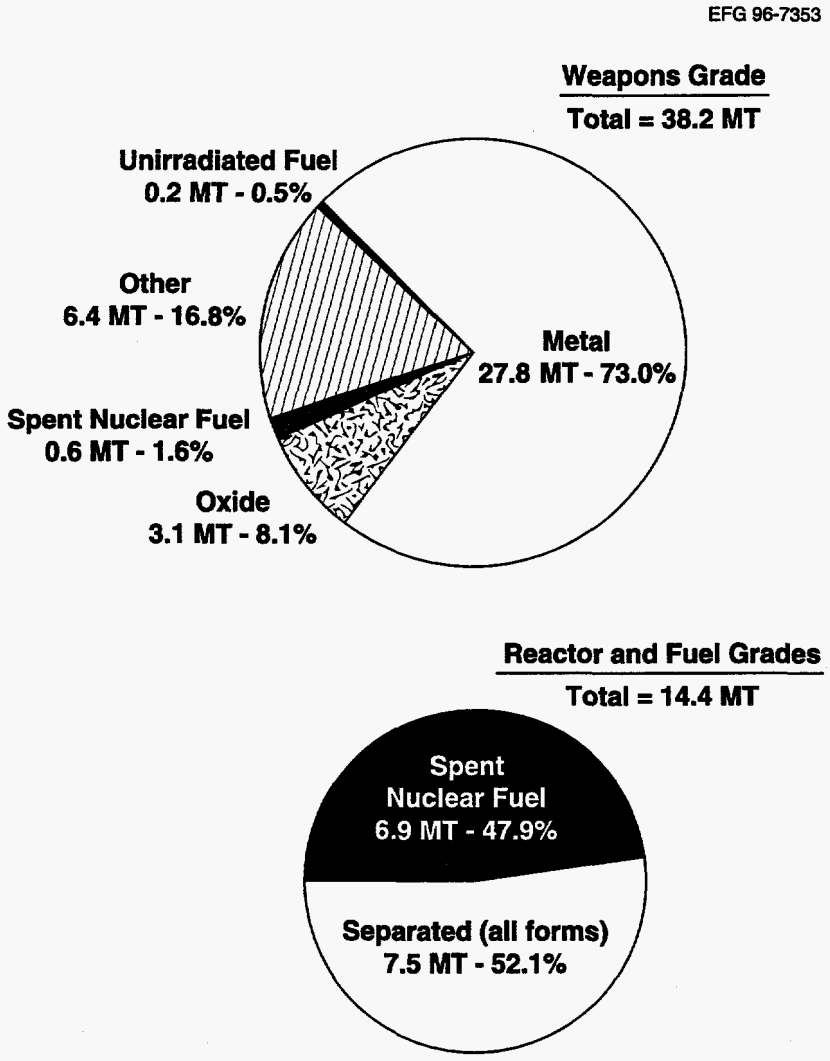


Figure F.2. Unclassified surplus plutonium by form. *Source*: DOE, *Taking Stock: A Look at the Opportunities and Challenges Posed by Inventories from the Cold War Era*, DOE/EM-0275, January 1996

Appendix G
Transportation and Packaging of Plutonium Material Forms

G.1 Overview

Disposition of 50 MT of excess weapons-grade plutonium as MOX fuel in nuclear reactors will require a series of sequential movements of the plutonium from its present locations (storage vaults at a number of DOE facilities) through the various processing, fabrication, and reactor facilities, and ultimately, emplacement as spent fuel at an HLW repository. Figure G.1 provides a simplified flowchart of the transportation segments associated with a reactor disposition alternative. Actual facility locations will be determined by DOE following the ROD. For analysis purposes, it has been assumed that the excess plutonium is in interim storage at many locations within the DOE complex. This material is first packaged and transported to a plutonium processing facility (assumed to be located at SRS), where the material is converted to PuO_2. The PuO_2 is then repackaged and transported to the MOX fuel fabrication plant (assumed to be constructed in an existing building elsewhere on SRS). Once fabricated, the fresh MOX fuel is packaged and transported to the reactor. These reactors are assumed to be federally owned and constructed on an existing federal site. Spent fuel discharged from each reactor is first stored in spent fuel pools at each reactor for 10 years. Ultimately, the spent fuel is packaged and transported to an HLW repository for emplacement in a geologic repository.

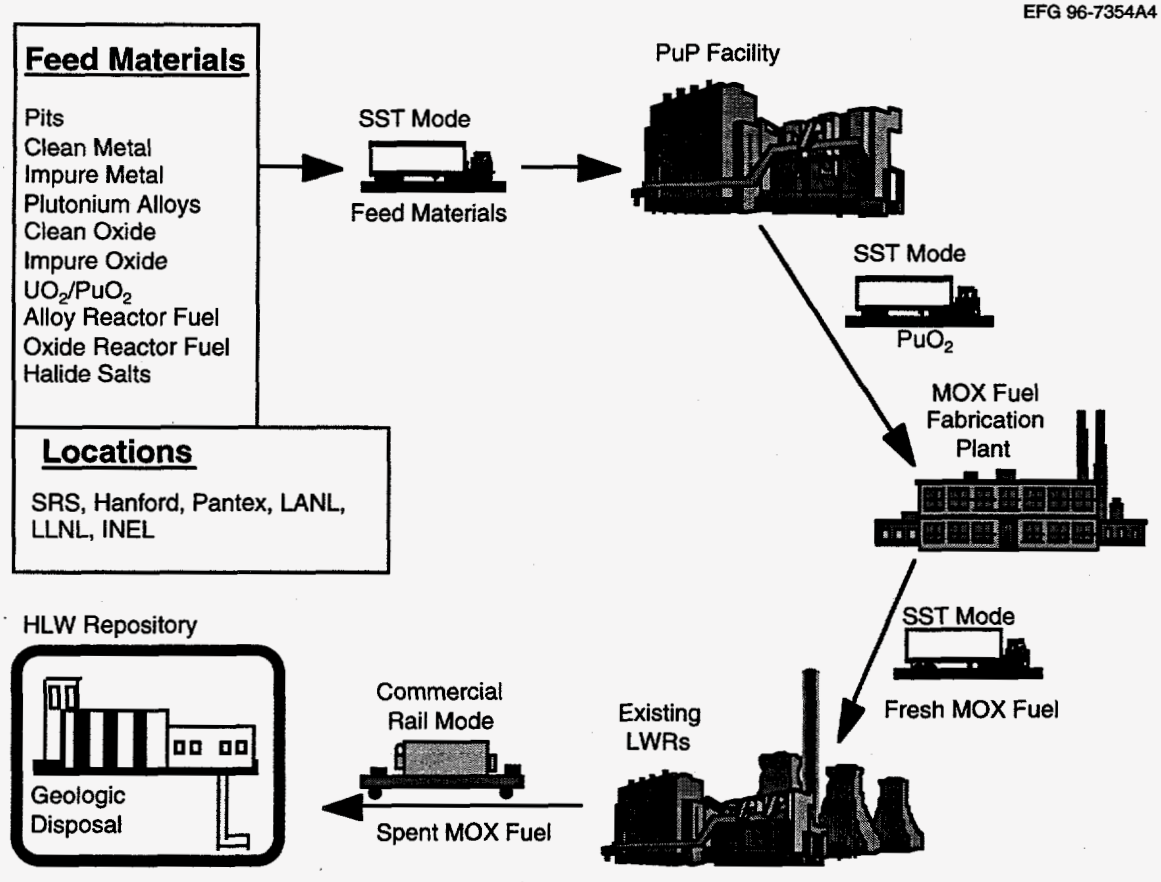


Figure G.1. Simplified flowchart showing transportation segments for reactor alternatives

Packaging and transportation of radioactive materials (e.g., plutonium, spent nuclear fuel, and associated radioactive wastes) are subject to the regulations of the Department of Transportation (DOT), NRC, and DOE. The following sections discuss applicable radioactive material transportation regulations and the safety of packaging and transporting radioactive materials. Finally, each transport leg associated with the reactor alternative is described in terms of the packaging needed and the number of shipments to occur over the duration of the alternative.

G.2 Regulations

Packaging and transportation of even low levels of radioactive materials are strictly regulated by the DOT and the NRC. DOE also controls packaging and transportation of radioactive materials under its control through a series of DOE orders. FMDP has assumed that most existing DOE facilities will continue their compliance with DOE orders, DNFSB as the reviewing agency. New facilities, however, would be licensed by the NRC.

NRC regulations establish requirements for the packaging and transportation of radioactive materials (10 CFR Part 71), including the preparations and procedures for shipment of licensed nuclear materials, procedures, and standards for obtaining NRC certification of packaging. In the case of weapons-grade plutonium, a quantity in excess of ~25 mg (8.8×10^{-4} oz.) constitutes a Type B quantity per 10 CFR Part 71. Therefore, all conceivable plutonium shipments with the FMDP program must use, at a minimum, a Type B package. 10 CFR Part 71 incorporates, by reference, DOT regulations 49 CFR Parts 170–189.

Additional NRC regulations pertain to the physical protection of nuclear materials at facilities and during transport operations (10 CFR Part 73). DOE also requires physical protection and control of nuclear materials, per DOE Order 5633.3B. Security requirements for the transport of nuclear materials by DOE are provided in DOE Order 5632.1C, as provided by DOE's Transportation Safeguards System. Requirements for off-site transport of radioactive materials are prescribed in DOE Order 460.1 or 5610.12, depending on the type of material. To provide security for shipment of special nuclear materials and weapons components, DOE's Transportation Safeguards Division operates SSTs that provide additional protection for special nuclear materials while in transit. Figure G.2 is a picture of a typical SST and tractor operated by DOE. SSTs are accompanied by armed escort vehicles. The design of the SST and operation of the SST fleet by DOE have been judged to significantly exceed the NRC's requirements for the physical protection of nuclear materials in transit, embodied in 10 CFR Part 73.

Although 49 CFR Part 173.7(b) provides the so-called national security exemption from the regulations, in Parts 170-189 of Title 49 for "shipments of radioactive materials, made by or under the direction or supervision of the Department of Energy or the Department of Defense, and which are escorted by personnel specifically designated by, or under the authority of those agencies, for the purpose of national security," it remains DOE's policy to comply with all DOT over-the-road requirements for which no overriding safety or security imperative exists. As noted in 49 CFR 173.7(d), "notwithstanding the requirements of sections 173.416 and 173.417 of this subchapter, packagings made by or under the direction of the U.S. Department of Energy may be used for the transportation of radioactive materials when evaluated, approved, and certified by the Department of Energy against packaging standards equivalent to those specified in 10 CFR Part 71. Packagings shipped in accordance with this paragraph shall be marked or otherwise prepared for shipment in a manner equivalent to that required by this subchapter for packagings approved by the NRC." In simplest terms, DOE maintains full compliance with packaging certification requirements and greatly exceeds NRC's physical protection requirements. DOE's SSTs, however, are exempted from placarding requirements required for hazardous materials shipments. However, additional safety, in the unlikely event of an accident involving an SST, is provided through the use of shipment monitoring and communication from a central control center. Local emergency response personnel would be immediately notified by DOE in the event of an accident.

G.3 Transportation Safety

Over the past two decades, the nuclear energy industry has safely transported more than 45 million packages of radioactive materials across the nation's highways and rail lines. Fewer than 3500 packages have been involved in accidents. Because of stringent regulations covering their packaging, only a few released any radiation. In every case, exposure levels were so low that there was negligible hazard to the public.

Figure G.2. Safe, secure trailer (SST) and tractor operated by DOE

Every year, about 100 million packages of hazardous materials are shipped in the United States. Most contain materials that are flammable, explosive, corrosive, or poisonous. Only about 3 % contain radioactive materials used for medical, research, and industrial purposes—mostly medical isotopes. For the most dangerous materials—high-level radioactive wastes and spent nuclear fuel—fewer than 100 shipments are made each year.

Safety from radioactive materials during transport is provided by use of containers that meet strict requirements. Even low levels of radioactive materials are packaged for shipment in strong, tight containers to protect the radioactive contents under a variety of transportation and accident conditions. Even more stringent requirements are imposed on shipments of highly radioactive materials, such as spent nuclear fuel. Spent fuel must be shipped in thick, stainless steel containers that can withstand the most severe accident conditions. Determination of the type of container needed is a function of the quantity and identity of the radionuclides to be shipped. For shipments containing radionuclides in quantities that exceed the Table of A_1 (for special form) or A_2 (for normal form) values (49 CFR 173.435 or 10 CFR 71, Appendix A), a Type B package is required. Spent fuel casks are Type B packages. For fissile materials, such as plutonium, many different acceptable Type B packages have been certified. Type B packages are carefully reviewed from design to fabrication before certification for use by either the NRC or DOE. Before certification, the container must meet rigorous engineering and safety criteria and pass a sequence of hypothetical accident conditions that create forces greater than a container will experience in actual accidents. Accident tests for Type B packages, administered in sequence, include

- a 9-m (30-ft) free fall onto an unyielding surface (which is equivalent to a crash into a concrete bridge abutment at 120 miles per hour), followed by

- a puncture test allowing the package to free-fall 1 m (40 in.) onto a steel rod 15 cm (6 in.) in diameter, followed by
- a 30-min exposure at 800°C (1475°F) that engulfs the entire package, followed by
- submergence of that same container under 0.9 m (3 ft) of water for 8 h.

A separate, undamaged container is also subjected to immersion in 15 m (50 ft) of water for 8 hours. For certification, a package must not release any of its contents during the hypothetical accident testing.

Figure G.3 shows the accident tests used for Type B packages. Many different containers have been successfully certified as Type B packages for radioactive materials. Each design provides considerable protection from the accidental release of radioactivity. To demonstrate that Type B packages (such as the robust packages used to transport spent nuclear fuel) can withstand a severe accident, DOE has performed a number of accident tests to simulate severe conditions. In Fig. G.4, the results of a severe accident involving crashing a tractor trailer carrying a package prototype into a massive concrete wall at 81 mph is shown. Although the truck was totally destroyed, damage to the package was external and superficial. The package remained intact, not releasing any of the material contained within the package. Analyses have shown that the hypothetical regulatory tests simulate literally all the mechanical and 99% of all thermal conditions that could realistically be experienced in the field. And because these hypothetical tests are performed in sequence, it is felt that the maximum level of conservatism has been achieved.

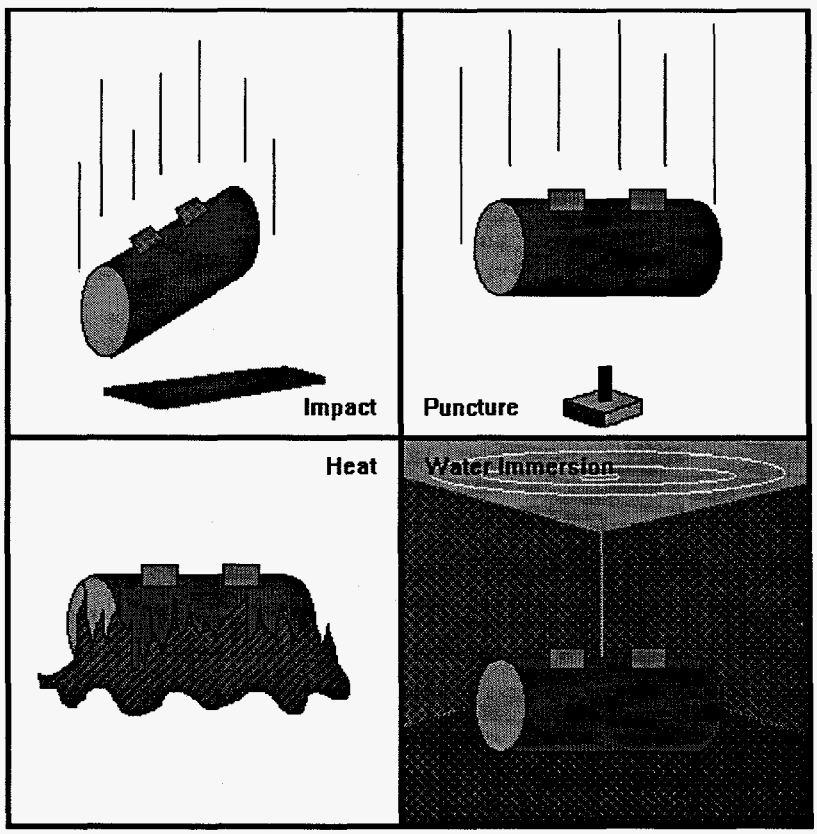


Figure G.3. Accident testing of Type B packages

Figure G.4. Spent fuel cask—results of crash testing

G.4 Transportation System

The transportation system, as described subsequently and previously shown in Fig. G.1, will require extensive use of DOE's SST fleet for the transport of all plutonium materials prior to their irradiation in the reactor. The quantity of plutonium to be shipped, in whatever form, has been determined to exceed the definition of strategic special nuclear materials (Category I). Category I quantities of special nuclear material (SNM) require the highest level of transport security, using special armored transport vehicles and other measures to ensure security (as specified in 10 CFR Part 73). At present, DOE's SSTs, which exceed the requirements of 10 CFR 73, are the only available packages in the U.S. The following sections describe shipment requirements on a leg-by-leg basis.

G.5 Feed Materials Transport Leg

As shown in Fig. G.1, excess fissile materials located at various DOE facilities include pits, clean metal, impure metal, plutonium alloys, clean oxide, impure oxide, U/PuO_2, alloy reactor fuel, oxide reactor fuel, and halide salts and oxides. Because of the variety of materials involved, no single Type B package design is appropriate. Therefore, DOE will use a number of different package designs.

Packages. Excess pits from dismantled nuclear weapons under the FMDP will be stored and transported in the Model FL or the newer AT-400A container. The various pits can use these containers by using different internal containers. The remaining (nonpit) weapons-grade plutonium is assumed to be in storage at various DOE facilities. This material is assumed to be stored in a form/storage container that meets the requirements of *The Criteria for the Safe Storage of Plutonium Metals and Oxides* stated in DOE-STD-3013 (also known as the "DOE 3013 Standard"). The criteria state that all plutonium metal and oxides (excluding pits) shall either (a) be sealed in a material container nested in a boundary container (until a primary containment vessel can be used) or (b) be sealed in a boundary container nested in a primary containment vessel (PCV). The design goal for the boundary container (like the traditional crimp-sealed "food can") and the PCV storage package is that the entire package should be maintenance free and be either compatible with a common transport package or transportable without additional repackaging.

Historically, DOE has used many different configurations of the DOT Specification 6M packages for the transport of plutonium (nonpit) materials. Such configurations, as specified in the *User's Guide for Shipping Type B Quantities of Radioactive and Fissile Material, Including Plutonium, in DOT 6M*

Specification Packaging Configurations, DOE/RL-94-68, September 1994, were approved for use by DOE. The DOT Specification 6M, as defined in 49 CFR 178.354, when used with a DOT Specification 2R inside containment vessel (per 49 CFR 178.360), as a "Specification Package" under DOT regulations is not required to undergo the formal certification process for new package designs. A typical Specification 6M package is shown in Fig. G.5. Figure G.6 shows a schematic of typical Specification 2R inner containers for the 6M package. Under NRC regulations, special requirements for plutonium shipments specify [per 10 CFR 71.63(b)] that plutonium shipments in excess of 20 curies (approximately 30 g for weapons-grade plutonium) must be shipped as a solid and must be shipped in an separate inner container that is placed within the outer packaging. The separate inner container must be demonstrated to be leak tight (not releasing its contents to a sensitivity of 10^{-6} A_2/h). Reactor fuel elements and metal or metal alloy forms of plutonium are exempt from this requirement. In terms of the Specification 6M package (including its Specification 2R inside containment vessel), the NRC regulations impose the additional requirement that for dispersible forms of plutonium, such as plutonium oxide, a "double containment" package is required.

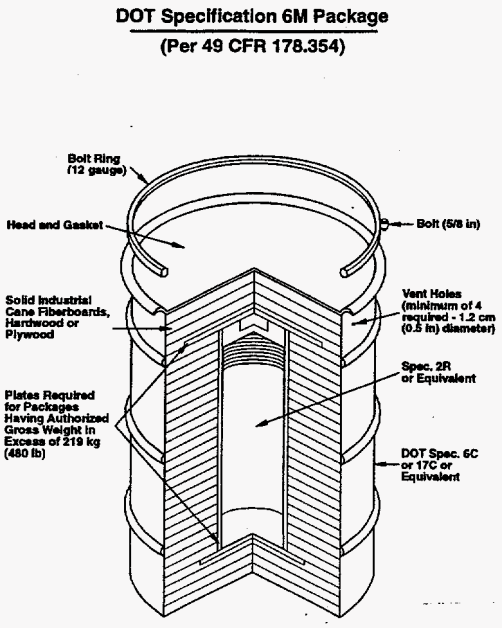


Figure G.5. Schematic of typical DOT Specification 6M package

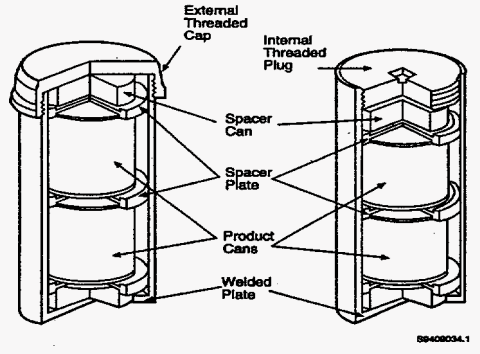


Figure G.6. Schematic of typical 2R inner containers for a Specification 6M package

Many new package designs, using either single or double containments, have been certified for use or are under development. Figure G.7 shows a cross-section view of the 9975 Package, a double-containment plutonium package developed by the Savannah River Company. The 9975 Package is just one of many new-generation packages that have been developed to provide the double containment necessary for nonmetal or nonalloy plutonium materials. Identification of the actual packages needed to ship the various plutonium materials (feed materials) from the various DOE storage locations to the plutonium processing facility will be performed at some point following the completion of DOE's implementation of the DNFSB's Recommendation 94-1 to stabilize the plutonium materials currently in storage.

G.6 PuO_2 Transport Leg

Following conversion of plutonium to PuO_2, the PuO_2 will be repackaged (using many of the same packages previously identified and shipped to the MOX fuel fabrication plant. The MOX fuel fabrication plant will operate on a schedule similar to the reactor operation schedule (between 10 and 18 years in most cases). This will require that some of the PuO_2 be placed in a lag storage vault because the shipment campaign will be completed in 10 years. The lag storage vault could be accommodated in the design of the MOX fuel fabrication plant design, or DOE could choose to use excess vault capacity at another DOE site that would be available.

Packages. Double-containment plutonium packages would be used for shipment of the PuO_2 from the PuP facility to the MOX fuel fabrication facility.

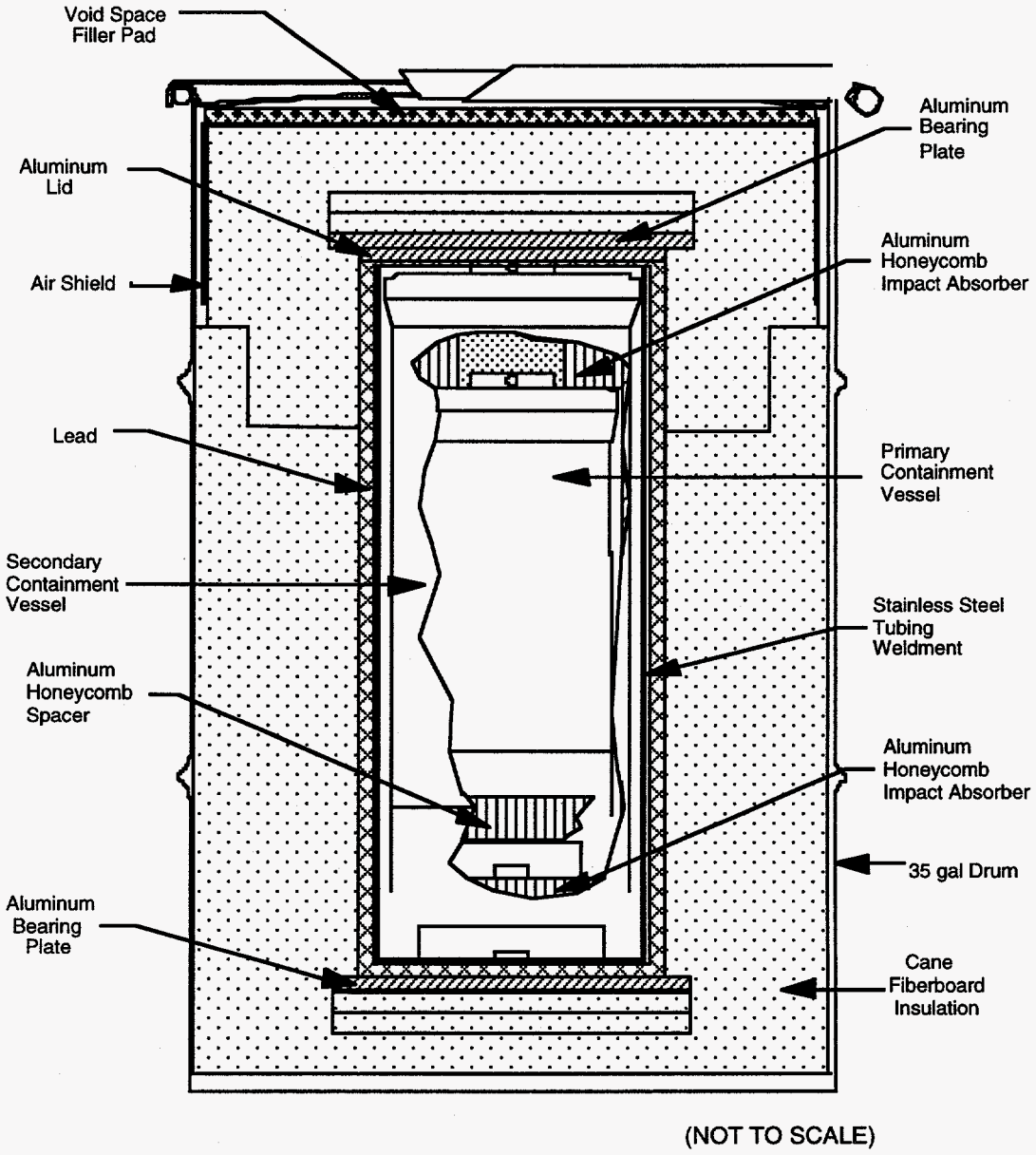


Figure G.7. Cross-section view of 9975 package

G.7 Fresh MOX Fuel Transport Leg

Approximately 1800 PWR, 9000 BWR, or over 100,000 CANDU MOX fuel bundles will be fabricated from the 50 MT of plutonium. The MOX fuel assemblies will be shipped from the MOX fuel fabrication facility to each of the reactors.

Packages. The MOX fuel assemblies will be shipped in a redesigned and recertified version of the Westinghouse Electric Corp. Model MO-1 package (Certificate of Compliance USA/9069/B). Currently, the MO-1 is certified to hold two PWR MOX assemblies per package—recertification may be required, depending on the fuel characteristics. Transport of the fresh MOX fuel (in MO-1 packages) will occur via SST. One MO-1 package (containing two assemblies) will be shipped per SST. The SST is required because of the quantity of fissile material contained in a package. Only a single MO-1 can be accommodated per SST, based only limitations of net payload and package dimensions.

CANDU MOX fuel bundles would also be shipped in SSTs. CANDU MOX bundles would be shipped in a Chalk River Nuclear Laboratory (CRNL) Model 4H package [Certificate of Compliance CDN/4212/B(U)F]. The Model 4H package holds four MOX CANDU bundles in a stainless steel 55-gal drum.

G.8 Spent MOX Fuel Transport Leg

Following irradiation, the spent fuel is stored at the reactor (first in the spent fuel pool, then in dry storage if needed) for a number of years before it is eventually transported to the candidate U.S. HLW repository. Once irradiated, the MOX fuel is no longer required to be shipped by SST. Instead, it is assumed that the Civilian Radioactive Waste Management System (CRWMS) transportation system will be used to transport the spent fuel from the reactors to the repository. Figure G.8 provides a representation of the Office of Civilian Radioactive Waste Management (OCRWM) Transportation System. This system includes truck and rail-based spent fuel cask systems. Some U.S. reactors that cannot accommodate large rail casks will need to use smaller spent fuel casks transported by truck. Figure G.9 shows an example of a recently developed truck cask, the GA-4. Such a cask would be transported on a tractor trailer, as shown in Fig. G.10. A photograph of a truck spent fuel cask is shown in Fig. G.11. The large donut-shaped protrusions on the ends of the package are impact limiters.

Packages. If possible this facility should be capable of handling a large rail cask, such as the canister system, as shown in Fig. G.12. The canister system can provide for the interim storage, transport, and final repository disposal of the spent fuel using a common sealed canister. The canister system is designed to allow the spent fuel to be sealed in a canister (40 BWR or Y-21 PWR assemblies). The sealed canister can then be either stored on-site (or at an interim storage facility), loaded into a transportation cask, and once at the repository, the canister is then sealed within a disposal cask for ultimate geologic emplacement. A representation of the canister and transportation cask is shown in Fig. G.13.

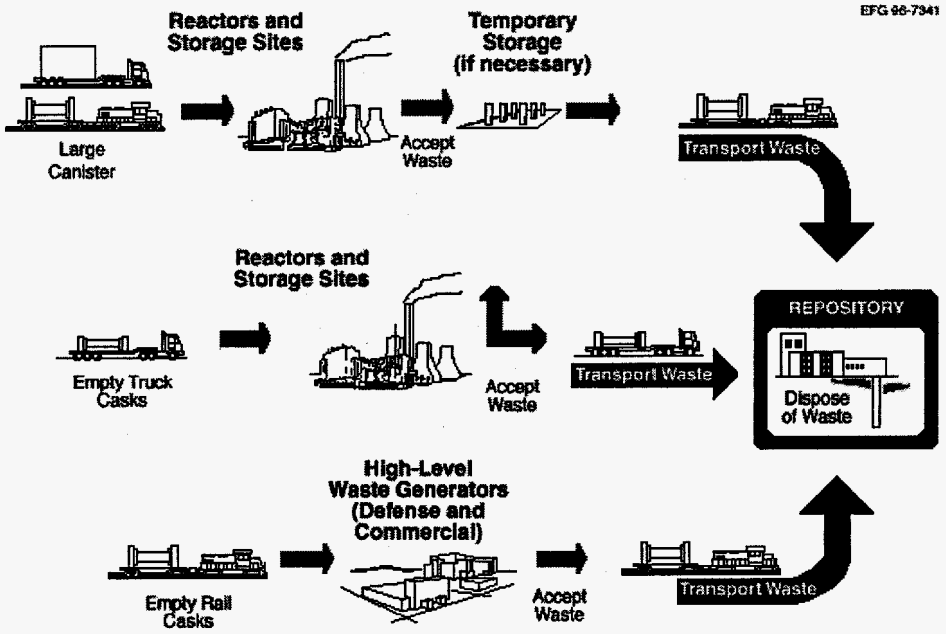


Figure G.8. Proposed OCRWM transportation system

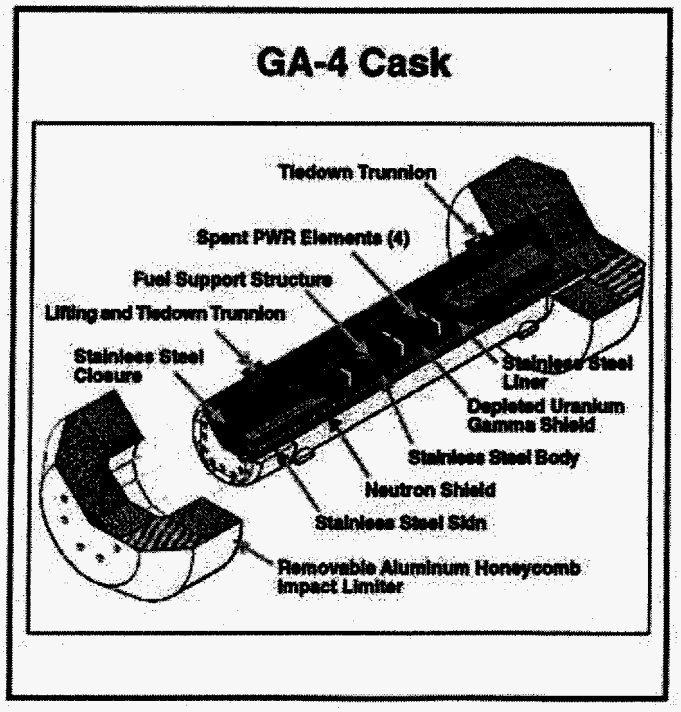


Figure G.9. Schematic of GA-4 truck cask for spent nuclear fuel

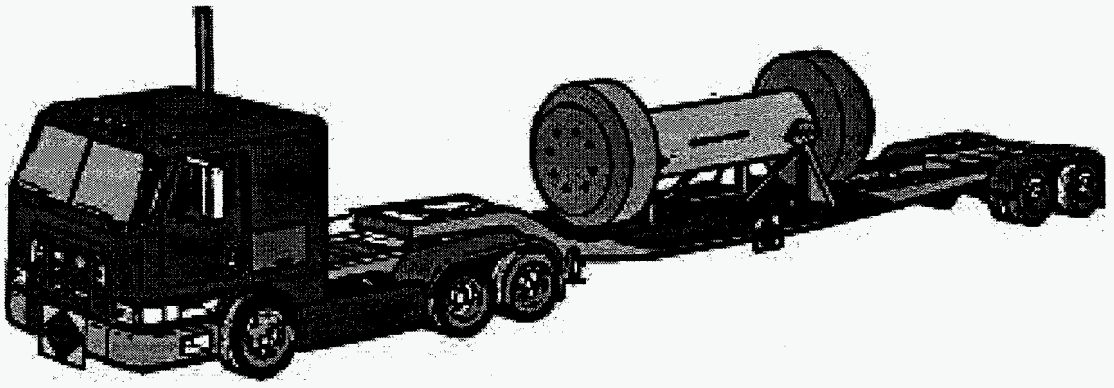


Figure G.10. Representation of GA-4 spent fuel cask loaded on truck

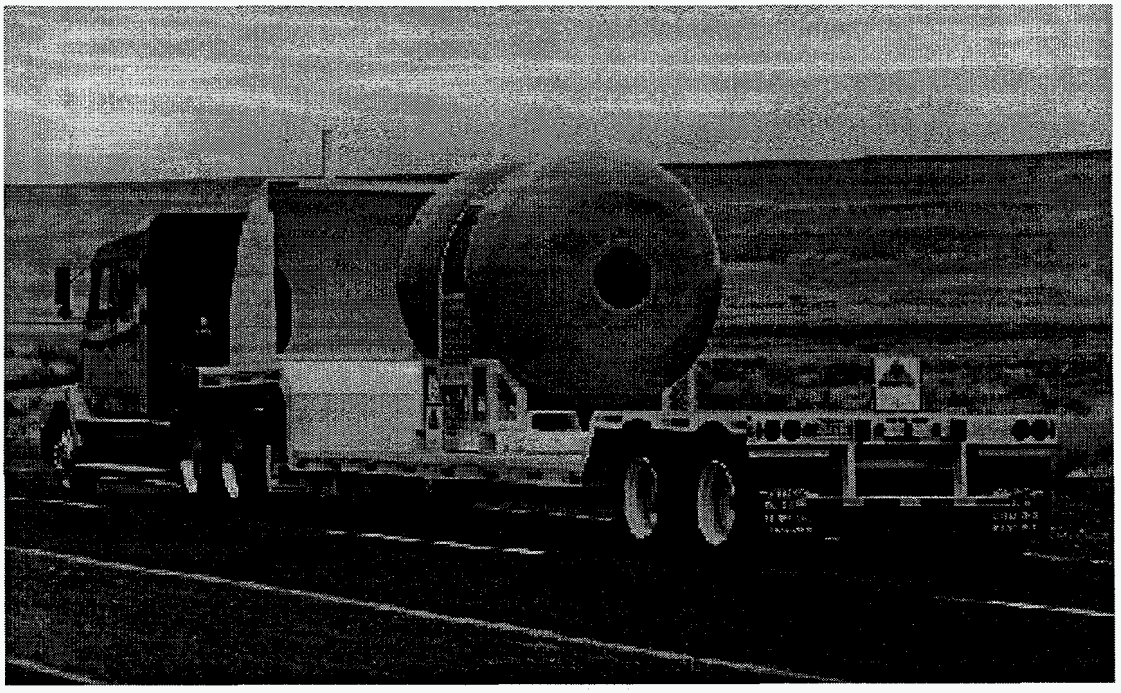


Figure G.11. Photo of spent fuel cask on truck

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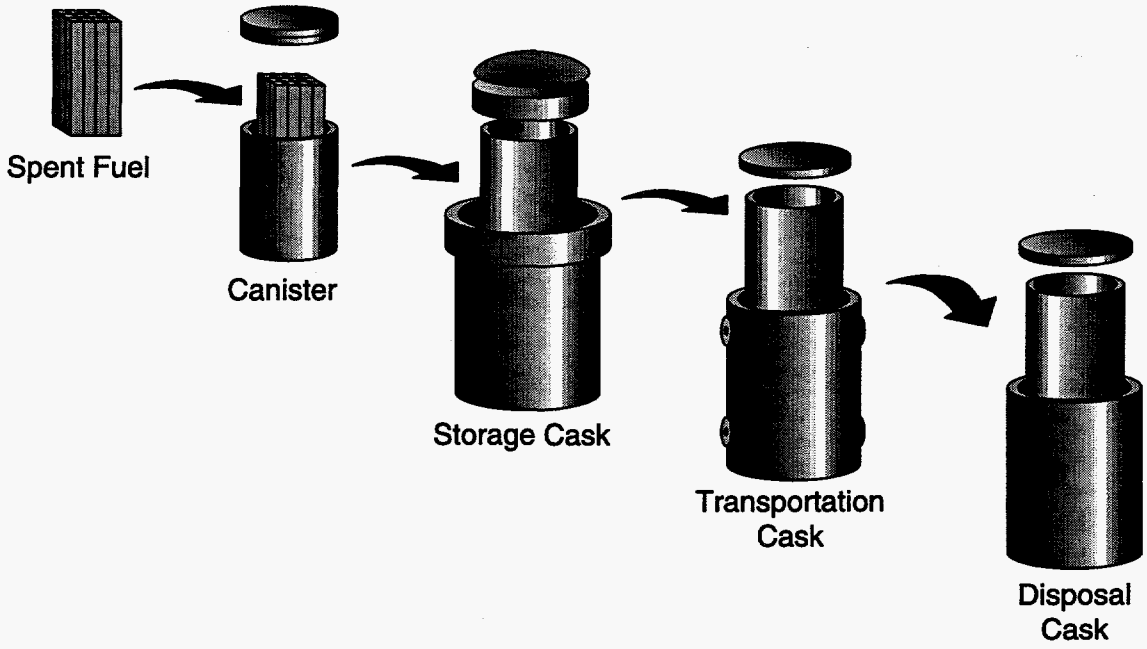

Figure G.12. Representation of canister system

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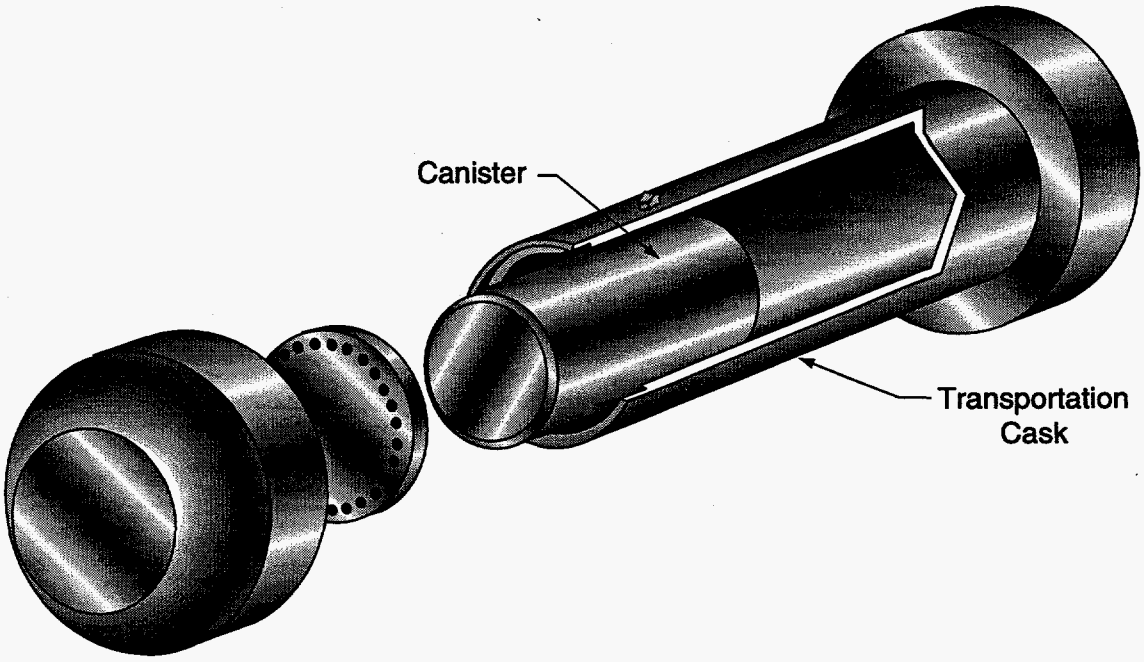

Figure G.13. Schematic of canister and transportation cask

Appendix H
Relationship of LCCs Presented in Chaps. 2–6 to Those in the July 17, 1996, DOE Technical Summary Report

H.1 Introduction

DOE's Technical Summary Report (TSR)[1] published July 17, 1996, contained alternative cost summaries based on preliminary cost estimates provided by the Reactor Alternative Team. Since that time, several improvements and minor modifications have been made in these cost and schedule estimates, and these revised estimates are presented in Chaps. 2–5 of this report. The major difference between the cost estimates in Chaps. 2–5 and those in the TSR is that the cost assessments in this report include the best estimate of a business-negotiable cost element, the utility incentive fee, which is not included in the TSR cost summaries. This appendix explains these differences and provides readers with the information necessary to relate these cost estimates to those presented in the July 17 TSR.

The preliminary existing reactor alternative cost estimates are summarized in Table 4-1 of the TSR (duplicated here as Table H.1). (TSR Table 4-1 rounds all LCCs to the nearest $10M, and the TSR term "operating cost" actually includes D&D costs.)

The hybrid variant is not discussed here because the immobilization/borehole LCC components were not discussed in Chap. 6 of this report.

H.2 Existing LWR Alternative Base Case

Tables H.2 and H.3 show the undiscounted and discounted LCCs that form the basis of the TSR Table 4-1 entry for this variant. Table H.4 shows how the inclusion of schedule effect changes and the incentive fee would modify the TSR undiscounted and discounted total LCCs to equate to those values in Sect. 2.6.2 of this report.

H.3 Existing LWR Private MOX Variant

The LCCs for this variant are not displayed in Table 4-1 of the July 17 TSR; however, the impacts of MOX fuel fabrication privatization are discussed in Sect. 4.2.2 of the TSR. Tables H.5 and H.6 show the cost data that would have been employed had the TSR included this variant in Table 4-1. Table H.7 shows how the inclusion of schedule effect changes and the incentive fee would modify the TSR undiscounted and discounted total LCCs to equate to those values in Sect. 3.6.2 of this report.

H.4 Existing LWR Collocated PuP/MOX Fabrication Variant (TSR Greenfield Variant)

Tables H.8 and H.9 show the undiscounted and discounted LCCs that form the basis of the TSR Table 4-1 entry for this variant. Table H.10 shows how the inclusion of schedule effect changes and the incentive fee would modify the TSR undiscounted and discounted total LCCs to equate to those values in Sect. 4.5.2 of this report.

H.5 Existing LWR Quick Start Variant

The LCCs for this variant are not displayed in Table 4-1 of the July 17 TSR, and the Quick Start variant costs were not explicitly discussed in Sect. 4.2.2 of the TSR. (Quick Start was discussed briefly from a schedule standpoint in Sect. 5.2.1 of the TSR.) Tables H.11 and H.12 show the cost data that would have been employed had the TSR included this variant in Table 4-1. Table H.13 shows how the inclusion of schedule effect changes and the incentive fee would modify the TSR undiscounted and discounted total LCCs to equate to those values in Sect. 5.6.2 of this report.

Reference

1. DOE, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, DOE/MD-0003, July 17, 1996.

Table H.1. Existing reactor alternatives

Reactor alternative	Facility	Constant ($M) Investment	Operating	Fuel[b] displacement credit	Net LCC	Discounted ($M)[a] Investment	Operating	Fuel[b] displacement credit	Net LCC
Existing LWRs, existing facilities	Front-end[a]	320	1090	0	1410				
	MOX fabrication	400	1010	–1390	20				
	Reactor	230	120	0	350				
	Total	950	2220	–1390	1780	690	1040	–660	1070
Existing LWRs, greenfield facilities[a]	Front-end[c]	1050	2590	–2010	1630				
	Reactor	330	130	0	460				
	Total	1380	2720	–2010	2090	950	1110	–820	1240
CANDU	Front-end[a]	320	1090	0	1410				
	MOX fabrication	450	1430	–320	1560				
	Reactor	100	40	0	140				
	Total	870	2560	–320	3110	630	1180	–150	1660

[a]Front end here is the same as plutonium processing.
[b]Same as MOX sales revenue at LEU equivalent price.
[c]Because the greenfield front-end and MOX fuel fabrication facilities are collocated in the existing reactor, greenfield variant, their costs are combined as front end in the table.
Source: Table 4-1 of July 17, 1996, TSR.

Table H.2. Summary of undiscounted LCCs for base case LWR option in TSR

Cost category description	LCCs to U.S. government (constant 1996 $M)			
	Facility			Total all facilities
	Plutonium processing	MOX	Reactor and repository	
Up-front (TPC)	322 (320)	400 (400)	232 (230)	954 (950)
Nonfuel O&M including government transportation	923	946	121	1990
D&D	169	60	0	229
Subtotal of O&M and D&D	1092 (1090)	1006 (1010)	121 (120)	2219 (2220)
Fee to utility owner or operator (reactor)			0	0
MOX revenues to government at LEU equivalent		–1387 (–1390)	0	–1387 (–1390)
TOTAL COST	$1414 (1410)	$19 (20)	$353 (350)	$1786 (1780)

Notes:
1. Basis for Table 4.1 of TSR. All costs in TSR Table 4-1 are rounded to the nearest $10M.
2. Operating costs in Table 4-1 of TSR include D&D costs.
3. Same schedule comment (*a*) as in Table H.3 applies.
4. Reactor operations cost in the TSR was based on 13.5-year duration.
5. Business-negotiable items are not included in TSR (i.e., no incentive fee).
6. The values in parentheses are the actual rounded entries in Table 4-1 of the TSR (reproduced as Table H.1 in this appendix).

Table H.3. Summary of discounted LCCs for base case LWR option in TSR

Cost category description	LCCs to U.S. government (discounted $M)			
	Facility			Total all facilities
	Plutonium processing	MOX	Reactor and repository	
Up-front (TPC)	240	287	160	687 (690)
Nonfuel O&M including government transportation	460	449	51[a]	960
D&D (government)	62	21	0	83
Subtotal of O&M and D&D	522	470	51	1043 (1040)
Fee to utility owner or operator (reactor)			0	0
MOX revenues at LEU equivalent (private reactor)		–658	0	–658 (–660)
TOTAL COST	$762	$99	$211	$1072 (1070)

[a]The TSR reactor operations schedule (13.5 years) was 10 months shorter and started later than the 14.3-year schedule used for the new RASR case in Table 2.34; thus, undiscounted O&M cost in the TSR is $5M smaller; the discounted cost in the TSR is also $5M lower because of its later start.

Notes:
1. Basis for Table 4-1 of TSR. (All costs in TSR Table 4-1 are rounded to the nearest $10M.)
2. Operating costs in Table 4-1 of TSR include D&D costs.
3. Business-negotiable items are not included in TSR (i.e., no incentive fee).
4. The values in parentheses are the actual rounded entries in Table 4-1 of the TSR (reproduced as Table H.1 in this appendix).

Table H.4. Comparison of TSR and RASR LCCs for existing LWR base case

	Undiscounted costs (1996 $M)	Discounted costs ($M)
Total LCC (TSR: Tables H.2 and H.3)	1786[a]	1072[a]
Addition of incentive fee to utility	433	231
Cost effect of schedule adjustment for reactor operations	5	5
Total LCC this report: RASR	$2224	$1308

[a]Total LCC values in Table 4-1 of the TSR were rounded to $1780M and $1070M, respectively.

Table H.5. Undiscounted LCC summary for private MOX LWR variant (TSR basis)

Major category description	LCCs to U.S. government (constant 1996 $M)			
	Facility			Total all facilities
	PuP	MOX	Reactor	
Up-front (TPC)	322	0	232	554
Nonfuel O&M, including government transportation	923	26	121	1070
Fee to utility owner or operator (reactor)			0	0
MOX purchase (private fabrication only)		2007	0	2007
D&D (government)	169	0	0	169
MOX revenues at LEU equivalent (private reactor)		–1387	0	–1387
TOTAL COST (TSR basis)	$1414	$646	$353	$2413

[a]The TSR reactor schedule is slightly different from that in Table 2.34 of this report. (See footnote *a* to Table H.3.)
Note: Business-negotiable items are not included in TSR (i.e., no incentive fee).

Table H.6. Discounted LCC summary for private MOX LWR variant (TSR basis)

Major category description	LCCs to U.S. government (discounted 1996 $M)			
	Facility			Total all facilities
	PuP	MOX	Reactor	
Up-front (TPC)	240	0	160	400
Nonfuel O&M, including government transportation	460	12	51	523
Fee to utility owner or operator (reactor)			0	0
MOX purchase (private fabrication only)		863	0	863
D&D (government)	62	0	0	62
MOX revenues at LEU equivalent (private reactor)		–597	0	–597
TOTAL COST (TSR basis)	$762	$278	$211	$1251

Note: This variant does not appear in the TSR; however, costs in this table share the base TSR assumption of not including business-negotiable cost categories such as the incentive fee.

Table H.7. Comparison of RASR and TSR LCCs for existing PWR private MOX variant

	Undiscounted costs (1996 $M)	Discounted costs ($M)
Total LCC (TSR basis: Tables H.5 and H.6)	2413[a]	1251
Addition of incentive fee to utility	433	204
Cost effect of schedule adjustments for reactor	+5	5
Total LCC (RASR basis)	$2851	$1460

[a]This value is $627M higher than the existing LWR options with government MOX plant in Table 4-1 of TSR. This is the source of the approximate $620M differential mentioned on pages 4–6 of the TSR. (TSR rounds to tens of millions.)

Table H.8. Summary of undiscounted LCCs for four-BWR collocated PuP/MOX TSR case

Cost category description	LCCs to U.S. government[a]				
	Collocated facility			Reactor	Total all facilities
	PuP portion	MOX portion	Subtotal PuP and MOX		
Up-front (TPC)	600	450	1050 (1050)	328 (330)	1378 (1380)
Nonfuel O&M, including government transportation[b]	655	1483	2138	126	2264
D&D	386	70	456	0	456
Subtotal of O&M and D&D costs[a]	1041	1553	2594 (2590)	126 (130)	2720 (2720)
Fee to utility owner or operator (reactor)[b,c]			0	0	0
MOX fuel revenues at LEU equivalent		–2006	–2006 (–2010)	0 (0)	–2006 (–2010)
TOTAL COST	$1641	–$3	$1638 (1630)	$454 (460)	$2092 (2090)
Mission years (TSR)	10	17[c]		17[b]	

[a]All costs in constant 1996 $M. LCCs in Table 4-1 of TSR were rounded to nearest $10M. Operations cost quoted in TSR includes D&D. Numbers in parentheses are actual rounded TSR values in Table H.1.

[b]In the TSR, the MOX facility and reactor mission were 17 years for purposes of economic evaluation (fee, transportation, staffing, and upgrades). In the TSR the MOX fabrication facility operated at one-half normal throughput for 2 years, thus the longer (17-year) operating schedule. Post-TSR loading schedule revisions now require 15.6 years for MOX fuel fabrication operations, as reflected in these cost tables. Post-TSR reactor schedule revisions now require 16.6 years for fee and transportation and 22.4 years for staffing and upgrades, as reflected in all cost tables in Chap. 4 of this report.

[c]The incentive fee is a business-negotiable item not included in the TSR but included in all tables in Chap. 4 of this report.

Table H.9. Summary of discounted LCCs for four-BWR collocated PuP/MOX TSR case

Cost category description	LCCs to U.S. government[a,b] (discounted $M)			
	Facility			Total all facilities
	Collocated		Reactor	
	PuP	MOX		
Up-front (TPC)	413	319	221	953 (950)
Nonfuel O&M, including government transportation[c]	311	604	50	965
D&D (government)	129	18	0	147
Subtotal of O&M and D&D costs[a]	440	622	50	1112 (1110)
Fee to utility owner or operator (reactor)[c,d]			0	0
MOX purchase (private fabrication only)			0	0
MOX revenues at LEU equivalent (private reactor)		–817	0	–817 (–820)
TOTAL COST	$853	$124	$271	$1248 (1240)

[a]LCCs in Table 4-1 of TSR were rounded to nearest $10M. Operations cost quoted in TSR includes D&D.
[b]Values in parentheses are rounded values appearing in Table 4-1 of TSR or Table H.1 of this appendix.
[c]In the TSR, the MOX facility and reactor mission were 17 years for purposes of economic evaluation (fee, transportation, staffing, and upgrades). Post-TSR loading schedule revisions now require 15.6 years for MOX fuel fabrication operations, as reflected in these cost tables. Post-TSR reactor schedule revisions now require 16.6 years for fee and transportation and 22.4 years for staffing and upgrades, as reflected in all cost tables in Chap. 4 of this report.
[d]The incentive fee is a business-negotiable item not included in the TSR but included in all previous tables in Chap. 4 of this report.

Table H.10. Comparison of TSR and RASR LCCs for four-BWR collocated PuP/MOX variant

	Undiscounted costs (1996 $M)	Discounted costs ($M)
Total LCC (TSR)	2092	1248
Incentive fee to utility (not included in TSR)	482	173
MOX schedule revision cost effect (17 years to 15.6 years)[a]	–174	–84
Reactor operations schedule revisions (17 years to 22.4 and 16.6 years)[b]	24	14
TOTAL LCC (RASR)	$2424	$1351

[a]MOX facility schedule was revised to reflect potential schedule improvements after initial submittal of data.
[b]The incremental cost of staffing the reactor will start with the arrival of the first MOX fuel bundle and will continue until the last MOX fuel bundle is removed from the reactor core (22.4 years). In the TSR, the MOX facility and reactor mission were 17 years for purposes of economic evaluation (fee, transportation, staffing, and upgrades). Post-TSR loading schedule revisions now require 15.6 years for MOX fuel fabrication operations, as reflected in these cost tables. Post-TSR reactor schedule revisions now require 16.6 years for fee and transportation and 22.4 years for staffing and upgrades, as reflected in all cost tables.

Table H.11. Undiscounted LCC summary for LWR Quick Start variant (on cost basis used in TSR[a])

Cost category description	LCCs to U.S. government (constant 1996 $M)			
	Facility			Total all facilities
	Plutonium processing	MOX	Reactor	
Up-front (TPC) including port MOX storage	336	410	232	978
Nonfuel O&M including government transportation	944	826	118	1888
Fee to utility owner or operator (reactor)[b]			0	0
MOX purchase (Eurofab)		237	0	237
D&D (government)	169	60	0	229
MOX revenues at LEU equivalent (private reactor)		–1387	0	–1387
TOTAL COST	$1449	$146	$350	$1945

[a]The TSR utilized a 13.1-year reactor staffing duration and a 9.2-year PuP operating duration. For this report (and all tables to this point), the reactor staff duration was adjusted to 17.6 years and the PuP operations to 8.5 years.
[b]Business-negotiable costs such as incentive fees were not considered in Chap. 4 of TSR.

Table H.12. Discounted LCC summary for LWR Quick Start variant (on cost basis used in TSR[a])

Cost category description	LCCs to U.S. government (discounted $M)			
	Facility			Total all facilities
	Plutonium processing	MOX	Reactor	
Up-front (TPC) including MOX storage	253	293	160	706
Nonfuel O&M including government transportation	513	409	55	977
Fee to utility owner or operator (reactor)[b]			0	0
MOX purchase (private fabrication only)		173	0	173
D&D (government)	66	23	0	89
MOX revenues at LEU equivalent (private reactor)		–725	0	–725
TOTAL COST	$832	$173	$215	$1220

[a]The TSR utilized a 13.1-year reactor staffing duration and a 9.2-year PuP operating duration. For this report (and all tables to this point), the reactor staff duration was adjusted to 17.6 years and the PuP operations to 8.5 years.
[b]Business-negotiable costs such as incentive fees were not considered in Chap. 4 of TSR.

Table H.13. Comparison of undiscounted RASR and discounted TSR LCCs for existing PWR Quick Start case

	Undiscounted costs (1996 $M)	Discounted costs ($M)
Total LCC shown in TSR (Tables H.11 and H.12)	1945	1220
Addition of incentive fee to utility	515	229
Post-TSR schedule corrections: • Reactor staffing duration increased from 13.1 years to 17.6 years • PuP facility schedule duration reduced from 9.2 years to 8.5 years	28 –59	11 –18
Total LCC shown in RASR	$2429	$1442

Appendix I
Glossary

Actinides: Radioactive elements with atomic number larger than 88 (i.e., 89 or higher).

Alternative: A term used during FMDP Phase II to define a group of pathways through a baseline set of facilities. Currently "alternative" is defined by reactor type.

Aqueous Process: An operation involving chemicals dissolved in water.

Architect and Engineer Contractor (AE): The organization responsible for incorporating process and manufacturing technology requirements into the design of facilities.

Attribute: A measurable relevant characteristic of an option, such as public acceptability or technical risk.

Boiling-Water Reactor (BWR): BWR is a type of LWR whose primary coolant is permitted to boil. The primary loops are typically under about 1000 psi of pressure.

Burn: To consume fissile materials in a reactor through fission.

Canyon: A remotely operated, heavily shielded plutonium or uranium processing facility.

Construction Contractor: The organization responsible for construction of new or modified facilities.

Conversion: An operation for changing material from one form, use, or purpose to another.

Criticality: Pertaining to a critical mass (the least amount) of fissionable material that can achieve self-sustaining nuclear chain reactions.

Curie: A unit of radioactivity equal to that emitted by 1 g of pure radium.

Deuterium: An isotope of hydrogen used in the fusion reaction of a nuclear weapon.

Disassembly: The process of taking apart a nuclear warhead and removing the subassemblies, components, and individual parts.

Discard: To dispose of material as waste.

Dismantlement: The process of taking apart a nuclear warhead and removing the subassemblies, components, and individual parts.

Disposal: The process of placing waste in an interim or final repository.

Disposition: A process of use or disposal of materials that results in the remaining material being converted to a form that is substantially and inherently more proliferation-resistant than the original form.

Dissolution: The chemical dispersal of a solid throughout a liquid medium.

Fissile: The term "fissile" refers to nuclear materials that are fissionable by both slow (thermal) and fast neutrons. Fissile materials include ^{235}U, ^{233}U, ^{239}Pu, and ^{241}Pu. Materials such as ^{238}U and ^{232}Th, which can be converted into fissile materials, are called fertile materials. It should be noted that ^{232}Th, ^{238}U, and all plutonium isotopes are fissionable by fast neutrons but not by thermal (slow) neutrons. They are not called fissile materials but may be called fissionable materials. The term fissile also refers to material that can support nuclear detonation.

Fission: Fission occurs when a neutron bombards the nucleus of an atom and causes it to split into fragments and release energy.

Fissionable Material: Material whose nuclei fission when bombarded by neutrons.

Formerly Restricted Data: Classified information, defined in the Atomic Energy Act, that is shared by DOE and DoD and is related to the military utilization of nuclear weapons or energy. Decisions to declassify such data must be agreed upon by both agencies.

Fuel Grade: Mixed oxide with a plutonium concentration of 7 to 19%.

Hazardous Material: A substance that poses a risk to health, safety, and property.

Hazardous Waste: Waste that includes toxic materials, reactives, corrosives, flammables, and explosives. These materials can damage living tissue; they can pose a variety of health hazards and cause a wide range of effects.

Heavy Metal: Heavy metal refers to all the isotopes of Th, U, Np, Pu, Am, and Cm.

High-Level Waste (HLW): Highly radioactive waste material from the reprocessing of spent nuclear fuel (including liquid waste produced directly in reprocessing and any solid waste derived from the liquid) that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation. DOE is responsible for disposing of all HLW in the United States. HLW is highly radioactive and must be handled from behind heavy protective shielding.

Highly Enriched Uranium (HEU): Uranium enriched in the isotopic content of ^{235}U to greater than 20%, a concentration range usable for nuclear weapons.

Integral Fuel (or Depletable) Neutron Absorber: The excess reactivity, which is included in a fuel reactor to obtain a desired cycle length, can be reduced by the use of a integral fuel neutron absorber. This is an isotope having a large-absorption cross section, which is converted to an isotope of low-absorption cross section as the result of neutron absorption. The increase in reactivity due to the burnup of this neutron absorber compensates (to some extent) for the decrease in reactivity due to fuel burnup and the accumulation of fission-product poisons.

Interagency Working Group on Plutonium Disposition (IWG): An interagency group established by the President of the United States to conduct a comprehensive review of the options for disposing of surplus plutonium from nuclear weapons activities of the United States and the former Soviet Union.

Interim Storage: Safe, controlled, inspectable storage facilities and conditions that will be established in the near term and will remain in effect until the long-term storage or disposition actions are implemented.

Life Cycle Cost (LCC): The "cradle to grave" costs to the government for planning, designing, constructing, commissioning, operating, and decommissioning one or more facilities. Revenues and transportation costs are normally included.

Light-Water Reactor (LWR): There are two types of LWRs. One is a pressurized-water reactor (PWR) and the other is a BWR. Both are thermal reactors. All commercially operating reactors in the United States and most commercial reactors worldwide are LWRs.

Light-Water Reactor (Full MOX Fuel): An LWR with full MOX fuel rods, each containing a mixture or blend of UO_2 and PuO_2. Traditional programs of using plutonium in LWRs use partial, not full, MOX fuel.

Light-Water Reactor (Partial MOX Fuel): An LWR with partial MOX fuel contains some fuel rods that are blended with UO_2 and PuO_2 and some that only contain UO_2. The blended uranium and plutonium oxides typically account for one-third of the total number of fuel rods.

Low-Enriched Uranium (LEU): Naturally occurring uranium contains only about 0.7% ^{235}U and almost all of the rest is ^{238}U. LEU is enriched in the isotopic content of ^{235}U, greater than 0.712% but less than 20% of the total mass, for use as LWR fuel.

Low-Level Waste (LLW): Radioactive waste not classified as high-level waste, transuranic waste, spent nuclear fuel, or by-product material.

Management and Operating (M&O) Contractor: The organization responsible for process operations.

Metal: Plutonium ingots or buttons that have not been fabricated into parts.

Mixed Oxide (MOX): MOX refers to a physical blend of UO_2 and PuO_2.

Mixed Waste: Waste that is a combination of radioactive and hazardous materials.

More specifically, the Federal Facility Compliance Act (FFCA) of 1992 defines mixed waste as containing both hazardous waste and source, special nuclear, or by-product material subject to the Atomic Energy Act. Therefore, the term "mixed waste" does not include all hazardous waste containing radionuclides. For example, it does not include hazardous waste

containing naturally occurring or accelerator produced radioactive material.

Natural Uranium: Uranium with ^{235}U concentration of 0.711%, the average concentration of ^{235}U in uranium in the natural, pre-enriched state.

Operations-Funded Project Cost (OPC): The portion of total project cost (TPC) budgeted with operating funds rather than congressional line item funds. OPC normally includes R&D, NEPA, licensing, permitting, planning, conceptual design, postconstruction startup, and any contingency applied to these categories.

Operations Office: The on-site DOE organization responsible for management and oversight of production facilities, M&O contractors, and DOE laboratories.

Option: Term used during FMDP screening process to define a group of related alternative pathways through a specific set of facilities that takes surplus fissile material to complete disposition. See Alternative.

Other Life Cycle Costs: All life cycle costs not included in total project cost. These postcommissioning costs include operations and maintenance, staff, consumables, utilities, capital upgrades, waste disposal, oversight, fees, transportation, decontamination and decommissioning, and revenues if appropriate.

Oxidation: A chemical reaction in which, typically, an oxide is formed.

Oxide: A compound in which an element (such as plutonium) is bonded to oxygen.

Plutonium Pit: The core element of a nuclear weapon's "primary" or fission component. Pits are made of weapons-grade plutonium, principally ^{239}Pu, and surrounded by some type of casing.

Plutonium: Man-made element produced when uranium is irradiated in a reactor. Plutonium-239 is the most suitable isotope for constructing nuclear weapons.

Pressurized-Water Reactor (PWR): A PWR is a type of LWR whose primary coolant is not permitted to boil. The primary loops are typically under about 2000 psi of pressure.

Process: To extract, separate, or purify a substance by physical or chemical means (e.g., to remove actinides).

Proliferation: The spread of nuclear, biological, and chemical capabilities and the missiles to deliver them.

Rad (radiation absorbed dose): A basic unit of absorbed dose of ionizing radiation representing an amount of energy absorbed per unit of absorbing material, such as body tissue.

Radioactive Waste: Any waste material or combination of waste materials (solid, liquid, or gaseous) that contain radionuclides regulated under the Atomic Energy Act.

Radionuclide: Certain natural and man-made atomic species with unstable nuclei that can undergo spontaneous breakup or decay and, in the process, emit alpha, beta, or gamma radiation.

Reactor-Grade: Plutonium with a ^{240}Pu concentration greater than 19%.

Recast: The process of melting metal and casting into a mold.

Record of Decision (ROD): A concise public document, issued no sooner than 30 d after completion of a final environmental impact statement or programmatic environmental impact statement, stating the agency's decision on the proposed action evaluated in the document. The ROD is not considered to be an environmental document since the decision may consider other factors in addition to environmental ones.

Rem (roentgen equivalent, man): Unit of biological dose equivalent. The dose equivalent in "rem" is numerically equal to the absorbed dose in "rad" multiplied by necessary modifying factors.

Reprocessing: The chemical separation of spent reactor fuel into uranium, transuranic elements, and fission products.

Residue: Recoverable by-product from a manufacturing or purification process.

Restricted Data: Classified information defined by the Atomic Energy Act. Restricted Data are born classified, regardless of source.

Special Nuclear Material (SNM): As defined in the Atomic Energy Act," 'special nuclear materials' means (1) plutonium, uranium enriched in the isotope U^{233} or in the isotope U^{235}, and any other material which the Commission . . . determines to be special nuclear material, but does not include source material . . ."

Spent Fuel Standard (SFS): A disposal standard whereby weapons-usable plutonium is made as unattractive and inaccessible for retrieval and weapons use as the residual plutonium in spent fuel from commercial reactors.

Spent Fuel: Irradiated reactor fuel that is no longer useful as fuel.

Stabilize: To convert a compound, mixture, or solution to a nonreactive form.

Staging: An interim storage or gathering of items awaiting use, transportation, consumption, or other disposition.

Storage: Any method of keeping items while awaiting use, transportation, consumption, or other disposition.

Stored Weapon Standard: A level of security and accountability that is equivalent to that afforded a stored nuclear weapon.

Technology: A specific technical component that is a subset of a facility (e.g., use of the ARIES process to convert plutonium metal to PuO_2 as a step in the PuP facility).

Total Estimated Cost (TEC): The portion of total project cost (TPC) budgeted with congressional line item capital funds. TEC normally includes Title I, II, and III design; construction; construction management; initial spares; and any contingency applied to these categories. TEC costs are sometimes called "capital project costs."

Total Project Cost (TPC): The total of all "up-front" investment costs (TPC = OPC + TEC) required to bring a facility into full-capacity operation. TPC may include planning, R&D, ES&H studies, site qualification, QA, permitting, safety analysis, design, construction, project management, initial spare parts, start-up, and staff training.

Transparency: Exchange of information, access to facilities, and cooperative arrangements undertaken to provide ready observation and verification of defense or other activities.

Transuranic: Any element whose atomic number is higher than that of uranium. All transuranic elements are produced artificially and are radioactive.

Treatment: An operation necessary to prepare material for disposal.

Tritium: A radioactive gas, an isotope of hydrogen, that serves as a booster for the fusion reaction in the secondary component of a nuclear weapon.

Variant: Term used to define a different specific set of facilities within a baseline alternative.

Vitrification: Process of immobilizing radioactive material by encapsulating it into a glasslike solid.

Warhead: Explosive part of a nuclear weapons system. Warheads consist of nuclear materials, conventional high explosives, and related firing mechanisms.

Waste: A discardable residue from a manufacturing or purification process.

Weapons-Grade: Plutonium with a ^{240}Pu concentration less than 7%.

Weapons-Usable Fissile Materials: A specific set of nuclear materials that may be utilized in making a nuclear explosive for a weapon. Weapons-usable fissile materials include uranium with ^{235}U isotopic content of 20% or more plutonium of any isotopic composition, and other special nuclear materials. The term "weapons-usable fissile materials" does not include the fissile materials present in spent nuclear fuel or irradiated targets from reactors.

94-1 Sites: DOE reservations from which stabilized and packaged plutonium forms will be shipped to the FMDP plutonium processing facilities. 94-1 refers to the DNFSB order that regulates the DOE-EM treatment of existing plutonium forms.

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