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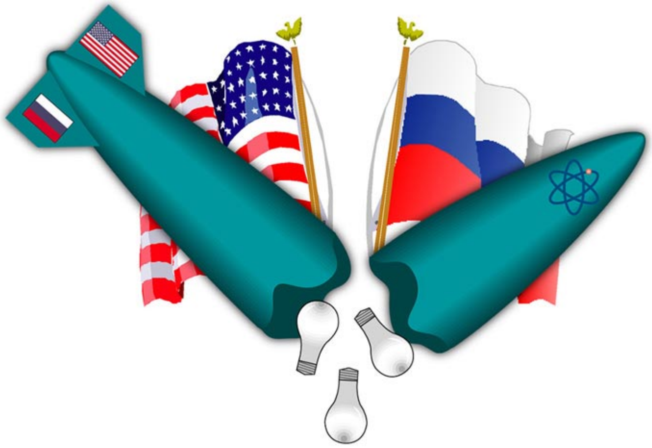
Life Cycle Costs for the Domestic Reactor-Based Plutonium Disposition Option

K. A. Williams



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LIFE CYCLE COSTS FOR THE DOMESTIC REACTOR-BASED PLUTONIUM DISPOSITION OPTION

K. A. Williams

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LIST OF ACRONYMS

ATR	Advanced Test Reactor (at INEEL)
CDR	conceptual design report
DCS	Duke/COGEMA/Stone & Webster, LLC (contractor)
DOE	U.S. Department of Energy
DP	Defense Programs (DOE)
DO-CDR	Design-Only Conceptual Design Report
DUF_6	depleted uranium hexafluoride
DUO_2	depleted uranium dioxide
EIS	environmental impact statement
EOL	end-of-life
F-D	Fluor-Daniel Group (architect-engineer)
FFF	fuel fabrication facility
FMDP	Fissile Materials Disposition Program (MD)
FY	fiscal year
GOCO	government-owned, contractor-operated
GFM	government-furnished material
GFS	government- furnished service
INEEL	Idaho National Energy and Environmental Laboratory
IGE	independent government estimate
LEU	low-enriched uranium
LANL	Los Alamos National Laboratory
LCC	life cycle cost
LWR	light-water reactor
MOX	mixed oxide
MOX FFF	MOX fuel fabrication facility
MT	metric ton
MTHM	metric ton of heavy metal (U + Pu)
NRC	Nuclear Regulatory Commission
NEPA	National Environmental Policy Act
ORNL	Oak Ridge National Laboratory
OPC	operations-funded costs
PORTS	Portsmouth Gaseous Diffusion Plant
PDCF	Pit Disassembly and Conversion Facility
PWR	pressurized-water reactor
PIE	postirradiation examination
PSAR	Preliminary Safety Analysis Report
ROD	Record of Decision
R&D	research and development
RASR	Reactor Alternative Summary Report
RW	DOE Office of Civilian Radioactive Waste Management
SRS	Savannah River Site
SST	safe, secure trailer
SWU	separative work unit (measure of uranium enrichment)
TA	technical area (at LANL)
TEC	total estimated cost (line-item)
TPC	total project cost (OPC + TEC)
TSR	technical summary report
UE	uranium enrichment
YM	Yucca Mountain
$M	millions of dollars

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K. A. Williams

ABSTRACT

Projected constant dollar life cycle cost (LCC) estimates are presented for the domestic reactor-based plutonium disposition program being managed by the U.S. Department of Energy Office of Fissile Materials Disposition (DOE/MD). The scope of the LCC estimate includes:

- design, construction, licensing, operation, and deactivation of a mixed-oxide (MOX) fuel fabrication facility (FFF) that will be used to purify and convert weapons-derived plutonium oxides to MOX fuel pellets and fabricate MOX fuel bundles for use in commercial pressurized-water reactors (PWRs);
- fuel qualification activities and modification of facilities required for manufacture of lead assemblies that will be used to qualify and license this MOX fuel; and
- modification, licensing, and operation of commercial PWRs to allow irradiation of a partial core of MOX fuel in combination with low-enriched uranium fuel.

The baseline cost elements used for this document are the same as those used for examination of the preferred sites described in the site-specific final environmental impact statement and in the DOE Record of Decision that will follow in late 1999. Cost data are separated by facilities, government accounting categories, contract phases, and expenditures anticipated by the various organizations who will participate in the program over a 20-year period. Total LCCs to DOE/MD are projected at approximately $1.4 billion for a 33-MT plutonium disposition mission.

1. INTRODUCTION

This report is a comprehensive update of several previous documents that provided life cycle cost (LCC) estimates for reactor-based plutonium disposition through the use of mixed-oxide (MOX) fuel. The reactor option was described in the U.S. Department of Energy Office of Fissile Materials Disposition (DOE/MD) programmatic Record of Decision (ROD)[1] published in January 1997. LCCs for the reactor option do not include costs associated with the Pit Disassembly and Conversion Facility (PDCF) nor those associated with the immobilization of any weapons-grade plutonium. PDCF and immobilization option LCCs are provided in *Plutonium Disposition Life Cycle Costs and Cost-Related Comment Resolution Document* (November 1999).[2]

This report will provide the background for the first complete public presentation of the reactor-based option LCCs since publication of two supporting documents that accompanied the 1997 ROD. These supporting documents were

- *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition* (DOE/MD-0003, October 1996),[3] and
- *FMDP Reactor Alternative Summary Report: Vol. 1—Existing LWR Alternative* (ORNL/TM-13275/V1, October 1996).[4]

An interim report, *Cost Analysis in Support of Site Selection for Surplus Weapons-Useable Plutonium Disposition* (DOE/MD-0009, July 1998),[5] presented the design, construction, licensing, and operation costs of two major facilities that would need to be constructed to support the plutonium disposition options. These facilities, the PDCF and the MOX fuel fabrication facility (FFF), were evaluated in this interim report for different candidate sites where the facilities might be located. Since the supporting contractor for the reactor-based option had not yet been chosen in 1998, costs related to fuel qualification, modification, and operation of candidate existing light-water reactors (LWRs) were not included.

The reactor-based option contractor, Duke/COGEMA/Stone & Webster (DCS), was selected and placed under DOE contract on March 22, 1999. This report, therefore, presents a more accurate and complete LCC estimate for the reactor option based on a collection, correction, and update of information from:

1. the documents cited above;

2. two design-only conceptual design reports (DO-CDRs): one for the PDCF[6] and one for the MOX FFF,[7] prepared by Fluor-Daniel (F-D) and Los Alamos National Laboratory (LANL);

3. an independent government estimate (IGE) prepared by Oak Ridge National Laboratory (ORNL) prior to negotiation of the mission base contract between DOE and DCS;[*] and

4. preliminary information obtained from DCS prior to completion of the contract statement of work, cost, and schedule baseline for the project.[*]

A preview of the cost and schedule baseline from the contractor's bid proposal* and the public *Environmental Synopsis Report*,[8] April 1999, were also used in preparation of this report.

The estimate presented here does not yet benefit from significant input from DCS or the Savannah River Site (SRS). It is an estimate derived from many sources and is constrained by the requirements of National Environmental Policy Act (NEPA) documentation, information in the DO-CDRs,[6,7] and other reference information used for preparation of the NEPA documentation. Cost data[2] for the PDCF and the Immobilization Facility were developed earlier by separate organizations within the DOE/MD. However, there has been a concerted effort to ensure that all cost-estimating categories, procedures, and guidelines were applied on a consistent basis, such that a clear picture of the overall LCCs for all activities within the plutonium disposition program is presented.

The development of this estimate has benefited from several iterations of "reasonableness review" by DOE project staff and by an independent architect/engineer firm. In this manner, the comparability of this estimate with those of other Fissile Materials Disposition Program (FMDP)-proposed plutonium-disposition facilities can be made more likely with regard to base assumptions and methods of presentation. Reviews were also done to assist in the consistent application of contingency or management reserve allowances across all projects.

An updated LCC estimate for the reactor option will be developed in the future. This new estimate will include information from the mission contractor design deliverables such as a Title I MOX FFF design and cost estimate and the project cost and schedule baseline developed from the contract statement of work. Preparation of other contract deliverables within the next 2 years, such as the reactor modification plan and the fuel qualification plan, will also contribute to refinement of the overall contract cost and schedule baseline.

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[*]These data sources cannot be released to the public because they contain procurement-sensitive information.

2. SCOPE OF ESTIMATE

2.1 FACILITIES

The facilities and activities covered in the scope of this estimate are illustrated in Fig. 1. Both the MOX fuel qualification project (production and irradiation of two lead assemblies) and disposition of 33-MT of weapons-grade plutonium (the baseline mission) are included. Existing weapons-grade plutonium dioxide powder and new powder derived from the pit disassembly and conversion demonstration at LANL will be used for fabrication of the lead assemblies in the Technical Area 55 (TA-55) at LANL. These two assemblies will be irradiated at the McGuire Nuclear Station, owned and operated by Duke Power Corporation. Postirradiation examination (PIE) of this lead assembly fuel will take place at ORNL per the preferred PIE site decision of November 12, 1999 (DOE Press release R-99-303).

Most of the 33 MT of plutonium to be dispositioned originates as metallic metal weapons parts or “pits” stored at Defense Programs’ (DP’s) Pantex facility in Amarillo, Texas. The DOE nuclear material transportation system will use its “safe, secure trailer” (SST) vehicles to transport the weapons parts and any other plutonium materials to the PDCF. The DOE SRS has been chosen as the preferred site for location of the PDCF. At the PDCF, the plutonium metal is converted to a PuO_2 powder. This powder may have retained some of the residual alloying components that were not totally removed by the pyrochemical processing in the PDCF. The powder is packaged at the PDCF and sent to the closely located MOX FFF. Evaluation of the LCCs for this report begins upon arrival of the PuO_2 at the MOX FFF. The FFF initial process is an aqueous polishing step intended to remove the residual impurities to acceptable levels and to produce an acceptable PuO_2 powder for use in the MOX fuel fabrication step. The clean PuO_2 is blended with clean depleted UO_2 powder to form a mixture that averages about 4.3% PuO_2. The mixture is formed into pellets, sintered, and loaded into rods that are then bundled into MOX fuel assemblies. These assemblies appear very similar to the low-enriched uranium (LEU) assemblies. After fabrication, the MOX assemblies are packaged in a special three-bundle shipping package and transported by SST to the six pressurized-water reactors (PWRs) that DCS has designated to provide irradiation services. The reactors to be used are three two-unit plants at the McGuire Nuclear Station (Duke Power Co.) just north of Charlotte, North Carolina; the Catawba Nuclear Station (Duke Power Co.) located near Lake Wylie, South Carolina; and the North Anna Nuclear Power Station (Virginia Power Co.) northwest of Richmond, Virginia. All MOX assemblies will be irradiated to a level equivalent or greater than the “spent fuel standard” concept advanced by the National Academy of Sciences (NAS). Once the spent MOX fuel is discharged from the reactors, it will be handled in the same way as spent LEU fuel. Spent fuel disposal is covered by a 1-mill/kWh fee paid by the utilities to the DOE Office of Civilian Radioactive Waste Management (RW). No additional costs are anticipated for disposal of MOX spent fuel compared to disposal of LEU spent fuel.

2.2 TEMPORAL SCOPE

LCCs presented here are projected costs for FY 2000 and beyond. Programmatic already-spent or “sunk” costs, which are also included in the final ROD documentation,[2] are listed separately as a single estimating category. Sunk costs were determined from DOE/MD budget records. Sunk costs for DCS activities are accumulated from the time of the signing of the DCS contract in March 1999. The major LCC categories considered in this report are remaining research and development (R&D), the fuel qualification project, development of management plan deliverables, and new facility design, modification design, startup, operation, deactivation, and ultimate decommissioning. Also included are effective credits to DOE for part of the value of the LEU fuel assemblies displaced by MOX fuel assemblies.

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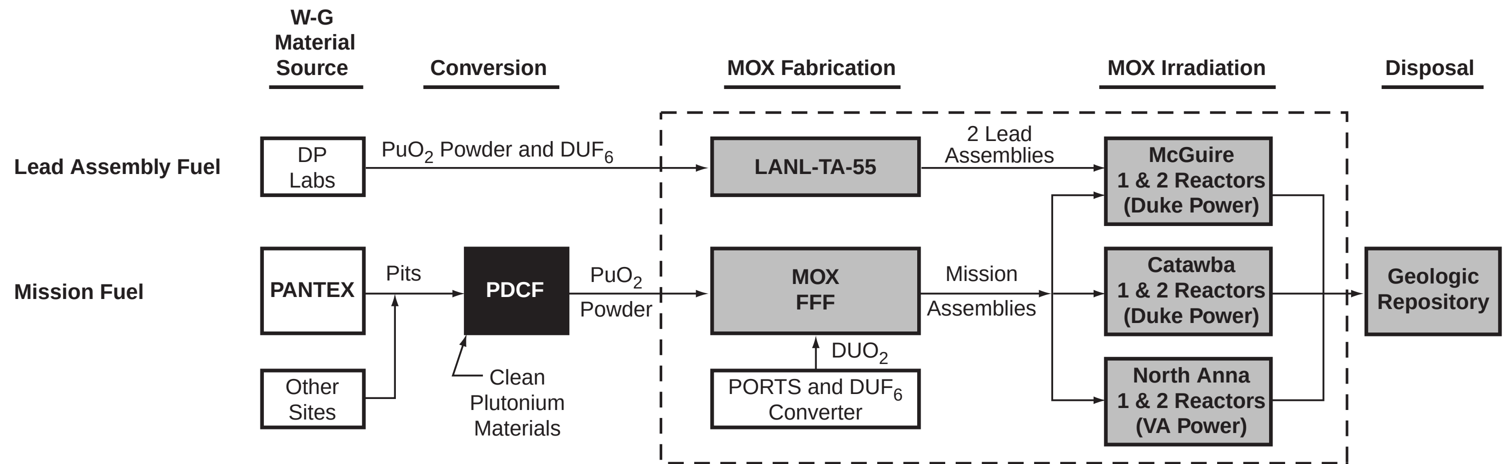

Mission Facilities	Origin of Pits	PDCF	MOX FFF	Commercial Reactors	Spent Fuel
Activity	Amarillo, TX	SRS	SRS	SC, NC, and VA	YM
Capacity	N/A	3.5 MT/year of plutonium	3.3 MT/year of plutonium or ~75 MT/year of heavy metal	164 Assemblies/year	
Years of Operation	N/A	9-10	10	10 years for Reload Batches for Loading 12 years for MOX Operations	
Ownership/Operations	GOCO	GOCO	DOE/DCS	Duke and Virginia Power	
Operations Start		2006	2006	2007	

--------	Encloses cost estimating scope of this report	SRS	Savannah River Site	PORTS	Portsmouth Gaseous Diffusion Plant (Ohio)
N/A	Not applicable	DUO_2	Depleted uranium dioxide		
GOCO	Government owned, contractor operated	DP	Defense Programs	YM	Yucca Mountain
DCS	Duke/Cogema/Stone & Webster, Inc.	LANL	Los Alamos National Laboratory	W-G	Weapons-grade (Pu)

Note: In addition to MOX mission assemblies shown above, LEU assemblies will be utilized to make up a reload batch of fuel.

Fig. 1. Reference facilities for reactor-based portion of dual-track plutonium disposition option.

3. LCC SUMMARY

Tables 1(a) and 1(b) show the major LCC elements for all facilities in lump sum FY 2000 constant million dollars and also provide word descriptions of the cost elements. Fuel qualification and new fuel transportation have been listed as separate activities. Projected costs for the MOX FFF Congressional line item project have been estimated separately from other up-front costs such as those associated with the modification, licensing and operation of the mission reactors. The up-front total cost for line items is referred to as total project cost (TPC). The TPC consists of two parts depending on the type of Congressional appropriation. Operations-funded project cost (OPC), funded out of the operating budget, and total estimated cost (TEC), funded out of the capital budget, are accumulated separately.

The remaining up-front costs (non-OPC) are funded out of the DOE operating budget for items that are not within the scope of a particular Congressionally authorized facility. Examples are DCS fuel qualification activities and modifications to privately owned reactors. The other major LCC elements are recurring costs, which for purposes of this estimate are assumed to remain the same in constant dollars for 10–12 years of the mission facilities lifetimes, and end-of-life (EOL) costs, which include final deactivation and decontamination and decommissioning (D&D) costs.

3.1 FUEL QUALIFICATION

The goal of the fuel qualification program is to successfully design, fabricate, irradiate, and examine two prototypic MOX PWR lead assemblies. The fuel qualification project is used to confirm to the regulatory authority that it is safe to use MOX fuel in U.S. reactors. The fuel qualification effort is a joint effort between DCS, the lead assembly fabrication site, and the national laboratory that will conduct supporting PIEs. The total cost of ~$120M for qualification of MOX fuel includes DCS management and fees, the lead assembly facility (preferred site is Building TA-55 at LANL) upgrades and operations, special process equipment to be provided by DCS, PIE at a national laboratory (preferred site is ORNL), preparation of documents to support the license amendment for insertion of the two lead assemblies in McGuire Unit-2, a programmatic contingency of 38.5% recommended for TA-55 activities, and a 10% management reserve for DCS fuel qualification activities. Duke Power Company irradiation fees at the McGuire Nuclear Station are also included. Approximately $56M (with contingency) of these funds are for TA-55 personnel services and TA-55 upgrades. Approximately $22M is for TA-55 facility “rent” from DOE/DP (infrastructure). The remaining $24M in fuel qualification costs are for DCS supervision and DCS-supplied special equipment plus PIE and NRC license amendment reviews.

3.2 MOX FFF

The documented design basis for the FFF project is currently the DO-CDR,[7] which was prepared in late 1997 and updated in 1998 to consider use of the SRS site. [The MOX FFF project baseline in the DO-CDR (technical cost and schedule) will eventually be replaced by the European MELOX-based plant design proposed by DCS. This new baseline plant concept will have an adjusted cost and schedule based on the evolving DCS design.] The DO-CDR MOX FFF design was based on a generic MOX plant design that was prepared for use in NEPA documentation, site evaluation, and submission of an out-year design budget for the reactor-based disposition program. The DO-CDR MOX FFF is capable of producing up to 195 Westinghouse-type PWR MOX fuel assemblies (similar to fuel to be used by DCS) annually and, for NEPA purposes, was assigned a mission time of 10 years. To accommodate six DCS PWRs, a fuel cycle requiring 164 assemblies per year was analyzed. For this estimate, a TPC (design, construction, and cold start-up cost) of $723M has been calculated from the SRS-sited DO-CDR estimate and includes the addition of design/construction cost data for the aqueous polishing portion of the MOX FFF building not included in the DO-CDR but covered separately in the final EIS.[9] Note that all DO-CDR derived costs have been escalated from 1997 constant dollars to 2000 constant dollars.

Table 1(a). Reactor-based disposition option LCC summary (FY 2000 constant $M)

	Column	(A)	(B)	C = (A + B)	(D)	E = (C + D)	(F)	(G)	(H)	I = (E + F + G + H)
		Up-front (investment) costs[a]					Mission recurring costs		EOL costs[b]	
Row No.	Facility/activity	OPC costs	Line item (TEC) costs	TPC costs	Other up-front costs	Total up-front costs	Operations costs	Fuel displacement credit	Deactivation/ D&D costs	Total LCC
	Reactor-based (33 MT of plutonium)									
1	Fuel qualification[c]				120	120				120
2	MOX FFF	157	566	723		723	763	–568	59	977
3	Existing reactors (6 PWRs)				136	136	150			286
4	Transportation				7	7	10			17
	Total	157	566	723	263	986	923	–568	59	1400

[a]OPC = Operations-funded up-front costs for MOX FFF design/construction project ($102M in sunk costs are also included in this category)
TEC = Total estimated cost (capital or Congressional line item funded cost for MOX FFF)
TPC = Total project cost for MOX FFF
Other “up-front” costs represent government investments for reactor modification and transportation equipment.
[b]EOL = End-of-life costs.
[c]Includes DCS management of fuel qualification activities plus management reserve. See Appendix A for content of categories.

Note: Column and row numbers are provided for traceability to Table 5 detailed categories and Table 1(b).

Table 1(b). Cost elements within Table 1(a) LCCs

Column and row	Name	Cost elements (cost numbers can be found in Table 5)
D1	Fuel qualification	Lead assembly program (LANL, DCS, and PIE costs), prorated DCS fee, lead assembly license amendment preparations and support, DOE management reserve
A2	MOX FFF OPC	Sunk costs, NRC activities, host site design support
B2	MOX FFF TEC	Design, license application, equipment procurement, construction, permits, construction management and fees, host site support, design reviews, inspections (Title III), DOE management reserve, cold startup
F2	MOX FFF operations	NRC inspections and regulation, labor, fuel assembly and other consumables, utilities, DUF_6 to DUO_2 conversion, waste disposal, hot startup, fee to DCS
G2	LEU displacement credit	Discounted value of displaced LEU fuel cycle materials and services
H2	MOX FFF deactivation and D&D	DCS deactivation costs, host site D&D costs for MOX FFF
D3	Reactor up-front costs	National laboratory reactor-related R&D, DCS home office management (base contract), reactor modification design and construction, core design and reload analysis, permits, reload license amendment, and DOE management reserve
F3	Reactor operations	Fee to contractor during option 2, incremental costs to utilities (additional people, casks, boron, control rods, etc.), additional enrichment cost for MOX adjacent LEU assemblies
D4	Transportation up-front costs	MO-1 lead assembly package recertification, mission shipping package design, certification, fabrication, and procurement
F4	Transportation operations	SST shipment of MOX bundles from MOX FFF to reactor sites

Recurring costs in the SRS-adjusted DO-CDR were estimated at $57M/year in 1997 dollars for 10 years and did not include an aqueous polishing step at the front end of the facility. This cost has been adjusted for escalation, a different imbedded fee structure, the addition of more than $11M/year for aqueous polishing, increased waste treatment, and altered use of consumables. Table 2 shows how the transition from the DO-CDR operations costs to the current costs have been accomplished. If the government operated this plant in the typical management and operating (M&O) contractor manner, where all M&O costs are reimbursed to the contractor, a cost of more than $62M/year would result, not including fees to the M&O contractor. As will be seen below, option 2 of the DOE mission contract provides for a different funding concept for MOX FFF operations, that is, one in which the contractor bears most of the cost risk.

3.3 FUEL DISPLACEMENT CREDIT

The use of partial MOX reloads is projected to save $86M/year (for 10 years for a total of $860M) in LEU fuel purchase costs for the LEU assemblies which were displaced by MOX assemblies. This savings assumes that LEU fuel costs are $1127/kgU based on the following LEU component costs: $12/lb U_3O_8 (ore), $5/kgU (natural U_3O_8 to UF_6 conversion), $90/SWU (enrichment service), and $180/kgU (PWR assembly fabrication). An enrichment tails assay of 0.3% ^{235}U is assumed along with a 10% carrying charge on the LEU assembly total cost. Table 3

Table 2. Adjustment of MOX FFF recurring costs from DO-CDR values to reflect revised mission

Expense	Annual cost	Comment
	Breakdown of DO-CDR MOX recurring (operations) costs (SRS revision)	
10 years of operations // 195 PWR assemblies/year	**(1997 $M/year)**	
Direct and indirect labor not including 10% fee	29.47	Based on staff of 350 without aqueous polish @ $84,200/year average
UF_6 to UO_2 conversion and transport to MOX FFF	0.50	DUF_6 to DUO_2 conversion service in $6–7/kgU range
Zirconium and stainless steel assembly hardware	11.20	Based on 195 PWR assemblies/year
Other consumables[a]	8.00	Based on 195 PWR assemblies/year
Regulation and inspection[b]	3.00	$3M/year in 1997 dollars per DO-CDR paid to NRC
Utilities (gas, water, electricity)[b,c]	0.50	Funded by DOE through site
Waste disposal[a,b,c]	1.30	Assumes no aqueous polishing
Imbedded fee (10% added to staffing by F-D)	2.95	To be replaced with consortium fee
Annual total per DO-CDR adjusted for SRS	56.92	
	Adjustment of DO-CDR MOX recurring (operations) costs[c]	
10 years of operations // 164 PWR assemblies: adjusted for aqueous polish, number of assemblies, fee	**(1999 $M/year)**	
Direct and indirect labor not including 10% fee markup (SRS)	30.20	Based on staff of 350 without aqueous polish @ $86,285/year (1999$)
Additional operations for aqueous polishing (SRS)	8.10	Adds 85 additional staff plus other in-plant costs
UF_6 to UO_2 conversion and transport to MOX FFF	0.50	Conversion service in $6–7/kgU range
Zirconium and stainless steel assembly hardware	9.42	Based on 164 PWR assemblies/year
Other consumables[a]	6.73	Based on 164 PWR assemblies/year
Regulation and inspection[b]	3.11	To be paid to NRC
Utilities (gas, water, electricity)[b,c]	0.52	To be in budget of SRS as GFS
Waste disposal[b,c]	3.17	Adds handling of additional wastes[d]
Imbedded fee (10% added to staffing by FD in DO-CDR)	0.00	To be replaced with consortium fee later
Total per adjustments	61.75	
	–6.80	Annual government supplied services (utilities, regulation, infrastructure, waste disposal)
	54.95	Annual costs to DCS

[a]Chemicals, maintenance materials. etc.
[b]Indicates government supplied service.
[c]Also to be in SRS budget as GFS.
[d]Table 5 escalates these to year 2000 constant dollars.

Table 3. Material and service components of LEU fuel displaced by MOX fuel

Commercial cost basis	Unit fuel assembly basis ($M)	Component (%)	Cost ($/kg LEU)
Uranium ore component	0.136	26.06	294
Conversion (U_3O_8 to UF_6) component	0.022	4.18	47
SWU component (enrichment)	0.234	44.70	504
Bundle fabrication UF_6 to UO_2	0.084	15.97	180
Carrying charge	0.048	9.09	102
Total	0.523	100.00	1127[a]

[a]Before any discounts to utility, value of all displaced LEU is ~$860M over mission life.

shows how the LEU costs break down on a per assembly and per kilogram of enriched uranium (EU) basis. The average enrichment of the LEU assemblies for an all-LEU core is assumed to be 4.17% ^{235}U which is typical of the fuel used in Duke Power Company PWRs. Because of the significant fuel savings, DOE has specified in its contract with DCS that DCS pay the majority of the MOX plant operational (recurring) cost. DCS has in turn requested a significant discount on the projected cost of the LEU displaced, that is, a reduced effective credit to the government. This discount is perceived to compensate the DCS participating utilities for the financial risk being taken to their multibillion dollar nuclear plant assets. The actual displacement credit will depend on the following factors: (1) the LEU constituent material and service prices at the time that the core reload order is made with the LEU fabricator, (2) the actual cost of operating the MOX FFF during the preceding operating cycle, (3) the fee required by the MOX FFF licensed operator, (4) cost/benefit sharing clauses in the DCS contract, and (5) the cost of government-furnished services (GFS) such as utilities and infrastructure cost from the FFF host site that have been provided by DOE. In simplistic terms, the government pays, or is paid, the difference between the discount-adjusted value of the LEU fuel displaced and the experienced cost of producing the MOX assemblies required for the reload. This will be a continuing issue because, on average, 2.5 reload batches of MOX fuel will be needed each year of operation. For the hypothetical case presented here, a credit of $568M is assumed. This credit reduces DOE's program cost for operation of the FFF from $763M to $195M for 10 years of MOX FFF operations including the cost of the original hot startup of the MOX FFF. This hypothetical credit represents a significant discount to the utilities on the market value ($860M) of displaced LEU fuel.

The actual multiplication factor (ratio of discounted LEU fuel value to the market LEU value) was negotiated between DOE and DCS. The factor is business sensitive and cannot be publicly released but is between 0.5 and 0.9. A value of approximately 0.7 was used in this estimate.

3.4 MOX FFF END-OF-LIFE COSTS

DCS will be responsible for deactivation of the MOX FFF after 10 years of operation. This task, which involves removal of process plutonium from the glove boxes and sealing of the boxes, has been assigned a ceiling cost to DOE of $10M. The actual price will be determined when option 3 of the DOE contract is negotiated.* An additional $49M will be needed by the host site for costs associated with removal of the equipment and glove boxes from the building, radwaste disposal,

*The DCS "base contract" covers design of the MOX FFF, design of reactor modifications, fuel qualification, and preparation and submittal of the MOX FFF license application. Contract option 1 covers MOX FFF construction and cold startup plus modification of reactors. Contract option 2 includes hot startup of the MOX FFF, "at-risk" (financial) operation of the MOX FFF, and incremental cost of operation of the six reactors on MOX fuel. Contract option 3 covers deactivation of the MOX FFF.

and return of the building to a habitable condition for possible use by other DOE missions. This amount also includes funding for the NRC to approve the deactivation plans.

3.5 IRRADIATION SERVICES

The ~$136M in nonfuel qualification reactor-related up-front costs are for core design, reactor system modification design, and actual modification and licensing of the six PWRs for use of partial MOX cores. The modification cost estimate is based on the 1996 Reactor Alternative Summary Report (RASR) studies.[4] In the future, DCS will produce a reactor modification plan and design concept that will provide a more accurate estimate of system modification costs. A new cost, schedule, and technical baseline for irradiation services will be developed within the next 2 years.

The $150M in projected operational costs and fees (to utilities and DCS home office) is spread over 12 years for reactor incremental operational costs, such as extra personnel, more boron chemical additions, and possible new types or additional control rods. Fuel loading costs are spread over 10 years to align with the period of MOX FFF operations and to avoid the storage of hundreds of MOX fuel assemblies; however, reactor operations, which are based upon utility commitments, etc., will probably dictate some variations from the base plan. There is also a small incremental charge related to the need to increase the amount of ^{235}U enrichment in LEU assemblies which are located adjacent to fresh MOX assemblies (4.3% ^{235}U vs 4.17% in an all-LEU core). This need is brought about to reduce neutron flux peaking at certain regions of the mixed core. This reactor physics-related difference results in additional uranium and enrichment charges to the utility from the LEU fabricator during the MOX mission.

The use of MOX in PWRs is not projected to impose any additional large facility deactivation, reactor D&D, or spent fuel disposal charges on the participating utilities. A $9M/year incremental operations charge (part of the $150M total above) is included to cover any additional boron chemicals, transportation or storage casks, control rods, etc., required by MOX use. Table 4 shows the fuel cycle parameters for the disposition mission assumed in this report.

3.6 TRANSPORTATION

A total mission cost of approximately $10M is projected for SST transport of the fresh MOX fuel assemblies from the MOX FFF to the three reactor sites. SRS was assumed as the point of origin. A special three-bundle transportation package to be designed and fabricated by DCS will be used. The up-front cost of acquiring the eight mission transportation packages is estimated at approximately $2M. The remaining $5M in up-front costs is assumed to cover contractor, national laboratory, and NRC shipping package certification activities.

3.7 LCC TABLES

Table 5 presents the LCCs in the same format used to prepare the DOE/MD LCC document[2] supporting the ROD and is designed to show how data from the MOX FFF DO-CDR were utilized. In that study,[2] similar cost categories are utilized to present PDCF and immobilization LCCs along with those for the reactor-based option. Total reactor-based LCCs are approximately $1.4 billion in constant FY 2000 dollars. These costs do not include the LCCs of the PDCF.

Table 6 compares the LCCs reported here to those projected in the 1996 ORNL RASR studies.[4] The reasons for the cost increases or decreases are shown on the table.

In summary, this new estimate is more accurate than the 1996 estimate because most data are now derived from conceptual design reports (the DO-CDR) and from projections made by the contractor, DCS, who will actually implement the program. It is also apparent that the risk-sharing consortium concept being implemented should result in significant savings to DOE and taxpayers over a hypothetical similar mission performed in the usual DOE GOCO contractor mode.

Table 4. Fuel cycle data on which LCCs (MOX FFF and irradiation services) are based

Attribute	Value	Comments
Total plutonium available for reactor-based disposition,[a] MT	33	Basic assumption in DO-CDR
Duration of operations for MOX FFF and initial loading of PWRs,[a] years	10	Basic assumption in DO-CDR
PWRs available[a]	6	Publicly announced by DCS[b] on March 22, 1999
HM mass of a fuel assembly, MT/assembly[a]	0.464	Typical mass of Westinghouse PWR assembly (HM)
PWR MOX assemblies/year per DO-CDR[a]	164	DO-CDR gives 195 as maximum for PWR, DCS suggests 164
Average throughput of MOX FFF, MT/year of HM	76.1	Calculated from two entries above
Annual plutonium throughput, MT/year	3.3	Calculated for 10-year campaign
Average plutonium concentration in HM (mass fraction) for MOX assemblies	0.0434	Calculated from two entries above
Average power capacity of PWR,[a] MW(e)	3411	Typical of Westinghouse reactor such as McGuire or Catawba
Fuel assemblies in PWR core (Westinghouse PWR)[a]	193	Typical of Westinghouse reactor such as McGuire or Catawba
Average time between refuelings, years	1.5	Typical of Westinghouse reactor such as McGuire or Catawba
Reloads per reactor over mission	6.67	Calculated
Total reloads for all reactors in mission	40	Calculated
Total assemblies (MOX + LEU) in a partial MOX PWR reload[a]	84	Typical of Westinghouse reactor such as McGuire or Catawba
Co-resident LEU assemblies in a partial MOX reload[a]	43	
LEU assemblies in an all-LEU reload[a]	84	
MOX assemblies available per reload (averaged)[c]	41	Calculated
Fraction of entire core that is MOX at equilibrium	0.49	Calculated (if mission load time were increased, this fraction would be lower)
Fraction of entire core that is reloaded at each refueling for MOX	0.44	Assumes MOX fuel twice burned
Fraction of all-LEU core that is reloaded at each refueling	0.44	Most fuel twice burned, some thrice burned
Average ^{235}U enrichment of all-LEU core (needed for LEU credit calculation)[a]	0.0417	Typical of Westinghouse reactor such as McGuire or Catawba
Average ^{235}U enrichment of co-resident LEU [surrounds MOX, needed for uranium enrichment (UE)-penalty calculation][a]	0.043	Typical of Westinghouse reactor such as McGuire or Catawba
LEU assemblies used in campaign if no MOX (for calculation of LEU reload value)	3360	Based on DCS data
Co-resident LEU assemblies used in MOX campaign (for calculation of UE-penalty)	1720	
LEU assemblies displaced by MOX during campaign (for calculation of displaced credit)	1640	

[a]Indicates that value is an input to model.
[b]Note: For simplicity all 6 DCS reactors are assumed to be the same size (in reality North Anna is somewhat smaller than Duke Power reactors).
[c]The actual fuel cycles will be designed by utilities to match their fuel requirements for their particular reloads. The actual reload configurations will be more complicated than represented in this illustrative example. The above idealized fuel cycle was designed to correspond to the NEPA MOX FFF 10-year operational requirement.

Table 5. Reactor program cost estimate summaries by major categories FY 2000 undiscounted dollars, including transitions from original MOX FFF DO-CDR

TITLE OF CATEGORY	ORIGINAL DO-CDR VALUE (1997$) NO AQUEOUS POLISHING	TRANSFORMED DO-CDR VALUE INCLUDES ESCALATION of DO-CDR TO FY2000	MOX FFF&IRRAD CONTRACTOR (DCS VALUE) (FY2000$)	VALUE SELECTED $ FOR ROD COST REPORT (FY 2000$)	SOURCE OF ESTIMATE	WSRC/SRO TASKS (Reviews & Oversight) (FY2000$)	LANL/LLNL/ ORNL & OTHER LAB SUPPORT (FY2000$)	Federal/DOE Costs (OTHER) Include NRC (FY2000$)	Total including Escalation (FY2000$)	Table 1 column and row
	(A)	(B)	(C)	(D=B or C)		(E)	(F)	(G)	(H=D+E+F+G)	
ENGINEERING OF MOX FFF										
DESIGN TITLE I & II (Non-Aqueous Polishing Portion)	$50,371,533	$51,530,078.26	$50,400,000	$50,400,000	DCS Base No				$50,400,000	
AQUEOUS POLISHING PORTION TITLE I &II			$12,600,000	$12,600,000	DCS (KAW)				$12,600,000	
OTHER: DCS MGT RES + LIC FEES + WSRC LIC SUPPORT				$8,782,000	DCS (KAW)	$1,000,000			$9,782,000	
MD MANAGEMENT RESERVE (10%) FOR ENGINEERING ACTIVITIES					HQ Guid.			$7,178,200	$7,178,200	
SUBTOTAL ENGINEERING	$50,371,533	$51,530,078	$64,130,078	$71,782,000		$1,000,000		$7,178,200	**$79,960,200**	
CONSTRUCTION OF MOX FFF										
EQUIPMENT (PROCUREMENT)	$88,587,740	$92,981,514.73		$92,981,515	DOCDR				$92,981,515	
SITEWORK	$9,953,508	$10,447,182.09		$10,447,182	DOCDR				$10,447,182	
PROCESS FACILITY PACKAGE	$68,851,119	$72,265,996.80		$72,265,997	DOCDR				$72,265,997	
SUPPORT FACILITY PACKAGE	$32,622,108	$34,240,099.31		$34,240,099	DOCDR				$34,240,099	
CONSTRUCTION CONTINGENCY 38.5%	$77,005,573	$80,824,895.28		$80,824,895	DOCDR				$80,824,895	
NON-NRC COMPLIANCE AND PERMITS	$1,950,000	$2,046,716.10		$2,046,716	DOCDR	$1,000,000			$3,046,716	
CONSTRUCTION LICENSING incl PSAR			$24,000,000	$24,000,000	DCS	$480,000			$24,480,000	
TITLE III	$15,209,937	$15,964,319.46		$15,964,319	DOCDR	$1,600,000			$17,564,319	
CONSTRUCTION CONTRACT AWARD FEE (6%) (assume separate construction contractor with M&O as manager)					NA					
AQUEOUS POLISHING ADD ON			$69,300,000	$69,300,000	DOE				$69,300,000	
TITLE III - Aqueous Polishing Add-On			$3,465,000	$3,465,000	DOE				$3,465,000	
CONSTRUCTION & PROJ. MANAGEMENT	$41,751,343	$43,822,126.11		$43,822,126	DOCDR				$43,822,126	
SRS SITE M&O CONSTRUCTION & PROJECT MANAGEMENT SUPPORT					KAW	$4,369,326			$4,369,326	
DCS FEE FOR CONSTRUCTION MANAGEMENT (7% ESTIMATED)			$29,360,395	$29,360,395	DCS				$29,360,395	
SUBTOTAL CONSTRUCTION	$335,931,328	$352,597,847	$126,125,395	$478,718,245		$7,449,326			**$486,167,571**	
								TEC=	**$566,127,771**	[2B]
OTHER PROJECT COSTS (OPC) - MOX FFF										
SUNK COSTS (SPENT PRIOR 1QTR.FY2000)					DOE			$102,296,000	$102,296,000	
NRC LICENSING ACTIVITIES					DOE			$3,500,000	$3,500,000	
SRS SUPPORT TO DESIGN (REQUIREMENTS DEFINITION)					KAW	$3,000,000			$3,000,000	
START UP (Cold) W/CONTINGENCY (Chosen ROD value: DO-CDR less $50M Hot Startup via DCS Option 2)		$48,223,583		$48,223,583	DOCDR	$500,000			$48,723,583	
SUBTOTAL OPC-MOX FFF		$48,223,583		$48,223,583		$3,500,000		$105,796,000	**$157,519,583**	[2A]
								TPC=	**$723,647,354** Including sunk costs	

[ ] Indicates column/row number of Table 1 subtotal that includes Table 5 entry.

Table 5. (continued)

TITLE OF CATEGORY	ORIGINAL DO-CDR VALUE (1997$) NO AQUEOUS POLISHING	TRANSFORMED DO-CDR VALUE INCLUDES ESCALATION of DO-CDR TO FY2000	MOX FFF&IRRAD CONTRACTOR (DCS VALUE) (FY2000$)	VALUE SELECTED $ FOR ROD COST REPORT (FY 2000$)	SOURCE OF ESTIMATE	WSRC/SRO TASKS (Reviews & Oversight) (FY2000$)	LANL/LLNL/ ORNL & OTHER LAB SUPPORT (FY2000$)	Federal/DOE Costs (OTHER) Include NRC (FY2000$)	
OPERATING COSTS OF MOX FFF (see Table 2 for transition from DOE-CDR):									
LICENSING DURING OPERATIONS (NRC Inspections/ a Gov't supplied service to DCS)	$30,000,000	$31,487,940			DOCDR			$31,487,940	$31,487,940
MOX-FFF LABOR (including aqueous polish) includes operations & maintenance	$315,560,000	$392,879,674		$392,879,674	DOCDR				$392,879,674
CONSUMABLES (non-rod/bundle parts) (and DOCDR: Maintenance of Equip)	$88,229,200	$69,031,385		$69,031,385	DOCDR				$69,031,385
UTILITY COSTS (a Gov't Supplied service to DCS via SRS)	$4,946,000				DOCDR	$5,309,550			$5,309,550
TRU / LLW DISPOSAL COSTS (A Gov't supplied service to DCS, incl aq polish wst, via SRS)	$13,000,000	$13,299,000		$13,299,000	DOCDR	$19,114,380			$32,413,380
UO2 CONVERSION	$4,950,000	$5,130,000		$5,130,000	DOCDR				$5,130,000
ROD &ASSEMBLY PARTS PURCHASED OFF-SITE	$112,500,000	$96,643,938		$96,643,938	DOCDR				$96,643,938
NOTE: TOTAL ABOVE OPERATING COSTS FROM SRS DOCDR = $569,185,800									
9 MO MOX-FFF HOT START & OPS(INCL AQUEOUS POL & GES/C)	$50,000,000	$51,300,000		$51,300,000	DOE DCS	$7,695,000		$3,100,000	$62,095,000
10 YR IMBEDDED "FEE" TO DCS FOR MOX OPERATIONS			$67,642,200	$67,642,200	DCS				$67,642,200
SUBTOTAL	$619,185,200	$659,771,937		$659,771,937		$32,118,930		$34,587,940	**$762,633,067**
DECOMMISSIONING (OPC) - MOX FFF									
DEACTIVATION OF MOX-FFF BY DCS			$10,000,000	$10,000,000	DCS				$10,000,000
DECOMMISSIONING (10% CONSTRUCTION $ minus DCS DEACTIV) BY SRS	$34,011,600				DOCDR DOE	$47,588,042			$47,588,042
FEE TO DCS-LLC DURING DEACTIVATION ($0.25M/YR)			$500,000	$500,000	DCS			$500,000	$1,000,000
SUBTOTAL	$34,011,600			$10,500,000		$47,588,042		$500,000	**$58,588,042**
REACTOR RELATED COSTS									
NON-FUEL QUAL: R&D SUPPORT (Mostly ORNL Reactor-related Tasks)	*				DCS		$24,100,000		$24,100,000
FUEL QUAL: TEST FUEL PROGRAM INCL. PIE AND ATR COSTS†	*								0
FUEL QUAL: LTA PROGRAM LTA FAB SITE (LANL/TA-55)	*				DCS		$78,038,500		$78,038,500
FUEL QUAL: LTA PROGRAM(DCS) INCL PIE(ORNL) & AQ POL	*		$22,100,000	$22,100,000	DCS		$2,000,000	$500,000	$24,600,000
SUBTOTAL - ONGOING DEVELOPMENT			$22,100,000	$22,100,000			$104,138,500	$500,000	**$126,738,500**

Table 5. (continued)

TITLE OF CATEGORY	ORIGINAL DO-CDR VALUE (1997$) NO AQUEOUS POLISHING	TRANSFORMED DO-CDR VALUE INCLUDES ESCALATION of DO-CDR TO FY2000	MOX FFF&IRRAD CONTRACTOR (DCS VALUE) (FY2000$)	VALUE SELECTED $ FOR ROD COST REPORT (FY 2000$)	SOURCE OF ESTIMATE	WSRC/SRO TASKS (Reviews & Oversight) (FY2000$)	LANL/LLNL/ ORNL & OTHER LAB SUPPORT (FY2000$)	Federal/DOE Costs (OTHER) Include NRC (FY2000$)	Total including Escalation (FY2000$)	Table 1 column and row
REACTOR RELATED COSTS (continued)										
5 YR DCS HOME OFFICE MANAGEMENT	*		$13,300,000	$13,300,000	DCS	$200,000			$13,500,000	[D3]
REACTOR MODIFICATION DESIGN & PLANNING	*		$10,500,000	$10,500,000	DCS		$200,000		$10,700,000	[D3]
REACTOR CORE DESIGN, MGT PLAN, & OPERATION PLAN	*		$3,400,000	$3,400,000	DCS		$400,000		$3,800,000	[D3]
REACTOR LIC. PLAN, LIC. AMENDMENT APPL, RL REPORT & PERMT'G	*		$2,700,000	$2,700,000	DCS		$200,000	$1,100,000	$4,000,000	[D3]
DESIGN/DEVELOPMENT/FAB/PROC OF LTA SHIPPING CASK (MO-1)	*		$500,000	$500,000	DCS		$500,000	$100,000	$1,100,000	[D4]
MISSION MOX TRANSPORTATION PLANNING & CASK CERTIFICATION	*		$100,000	$100,000	DCS		$4,000,000	$500,000	$4,600,000	[D4]
FEE TO CONTRACTOR FOR BASE CONTRACT (nonFFF related)	*		$4,189,000	$4,189,000	DCS				$4,189,000	[D1]
REACTOR MODIFICATION INCLUDING EQUIPMENT & SITE MODS	*		$75,001,207	$75,001,207	DCS				$75,001,207	[D3]
PROCUREMENT OF MISSION FRESH SH'PING CASKS	*		$1,500,000	$1,500,000	DCS				$1,500,000	[D4]
REACTOR LICENSE AMENDMENT ACTIVITIES NOT IN BASE CONTRACT	*		$2,700,000	$2,700,000	DCS		$1,000,000	$4,400,000	$8,100,000	[D1]
MD MANAGEMENT RESERVE FOR DCS BASE CONTRACT ACTIVITIES	*				DOE			$4,800,000	$4,800,000	[D1]
MD MANAGEMENT RESERVE FOR DCS OPTION-1 ACTIVITIES	*				DOE			$8,400,000	$8,400,000	[D3]
"FEE" TO DCS-LLC DURING OPTION 2	*		$12,000,000	$12,000,000	DCS				$12,000,000	[F3]
TRANSPORTATION OF PuO2 FROM PDCF TO MOX-FFF (N/A)	*				DOE				0	
TRANSPORTATION OF FRESH FUEL TO REACTOR (SST OPS)	*				DOE			$9,700,000	$9,700,000	[F4]
12 YR INCREMENTAL REACTOR OPERATIONS COSTS DUE TO USE OF MOX	*		$108,000,000	$108,000,000	DCS				$108,000,000	[F3]
COST OF ADDITIONAL ENRICHMENT/ORE (ABOVE ALL LEU) IMPOSED BY MOX FOR CO-RES LEU	*		$29,600,000	$29,600,000	DCS				$29,600,000	[F3]
INCREMENTAL POOL STORAGE/ON-SITE STORAGE/REPOSITORY COSTS FOR SF	*									
SUBTOTAL			$263,490,207	$263,490,207		$200,000	$6,300,000	$29,000,000	**$298,990,207**	
EFFECTIVE CREDITS TO GOVERNMENT - VALUE OF LEU RELOADS ADJUSTED FOR DISCOUNT (DOE COSTS ARE AUDIT COSTS)			($574,746,192)	($574,746,192)			$2,000,000	$5,000,000	**($567,746,192)**	[2G]
TOTAL ESTIMATED PROJECT COST	$1,131,516,977			$979,839,781		$91,856,297	$112,438,500	$182,562,140	**$1,402,850,979**	

[ ] Indicates column/row number of Table 1 subtotal that includes Table 5 entry.

	FROM ABOVE	ROUNDED COSTS*
SUNK COSTS	$102,296,000	$100,000,000
ONGOING DEVELOPMENT	$126,738,500	$125,000,000
DESIGN & CONSTRUCTION OF THE MOX FFF	$621,351,354	$620,000,000
OPERATIONS OF THE MOX FFF	$821,221,109	$820,000,000
EFFECTIVE VALUE OF FUEL	($567,746,192)	-$565,000,000
COST TO CONSTORTIUM REACTORS	$289,290,207	$290,000,000
TRANSPORTATION	$9,700,000	$10,000,000
TOTAL	$1,402,850,979	$1,400,000,000

*Basis of numbers appearing on Table ES-1 of Ref. 7.

Table 6. Comparison of 1996 RASR LCCs to those in this study

Facility or activity	1996 RASR cost[a] (1996 constant $M)	This study[a] (2000 constant $M)	Explanation of increased cost (or decreased credit)
Fuel qualification (a reactor-related cost in RASR)	36	120	More extensive fuel qualification program assumed.
MOX FFF	1111	1545	Aqueous polishing step added to scope. New building rather than existing building (RASR case) assumed.
LEU displacement credit	–925	–568	LEU value discounted to compensate utilities. RASR cost was not discounted.
Modified reactors (including transportation of bundles)	528	303	RASR assumed large irradiation fee based on $5M to $13M per reactor-year. This report gives incentive to utilities with discount on LEU value rather than by large irradiation fee.
Total	750	1400	

[a]Both cases assume 33-MT reactor-based plutonium mission. RASR LCCs formed the basis for the 1996 TSR (Ref. 3).

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