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COST ANALYSIS REPORT FOR THE LONG-TERM MANAGEMENT OF DEPLETED URANIUM HEXAFLUORIDE

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May 1997

Lawrence Livermore National Laboratory

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1. INTRODUCTION

With the publication of a Request for Recommendations and Advance Notice of Intent in the November 10, 1994, *Federal Register* (59 FR 56324 and 56325), the Department of Energy (DOE) initiated a program to assess alternative strategies for the long-term management or use of depleted uranium hexafluoride (UF_6) stored in the cylinder yards at Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee. The current management strategy entails handling, inspection, monitoring, and maintenance activities to ensure safe storage of the depleted UF_6. Six long-term management strategy alternatives are being analyzed in a draft Programmatic Environmental Impact Statement (PEIS) (DOE, forthcoming 1997). These alternatives include the current management strategy (the "No Action alternative"), two long-term storage alternatives, two use alternatives, and a disposal alternative. Complete management strategies may also involve transportation and, in many cases, conversion to another chemical form.

This *Cost Analysis Report* was developed to provide comparative cost data for the management strategy alternatives being examined. The draft PEIS and the *Cost Analysis Report* will be used by DOE in the decision-making process, which is expected to result in a Record of Decision in 1998, completing the first phase of the Depleted UF_6 Management Program, management strategy selection. During the second phase of the Program, site-specific and technology-specific issues will be addressed.

This report presents life-cycle cost estimates for each of the management strategy alternatives. The cost analysis estimates the primary capital and operating costs for the different alternatives and reflects all development, construction, operating, and decontamination and decommissioning (D&D) costs, as well as potential off-setting revenues from the sale of recycled materials. The costs are estimated at a scoping or preconceptual design level and are intended to assist decision makers in comparing alternatives. The focus is on identifying the relative differences in the costs of alternatives for purposes of comparison, not on developing absolute costs for project budgets or bid-document costs. The technical data upon which this cost analysis is based is principally found in the *Engineering Analysis Report* (Dubrin et al. 1997).

Section 2 of this report introduces the options and alternative strategies included in the draft PEIS. Section 3 presents the basis for the cost estimates for each of the options considered. Section 4 presents the cost estimates for the options. Section 5 presents the cost estimates for the alternative management strategies, which were developed by linking together the cost estimates for individual options. Section 6 discusses the uncertainty in the cost estimates for the alternative strategies and provides an analysis of the sensitivity of the cost estimates to a variety of assumptions.

2. OPTIONS AND ALTERNATIVE MANAGEMENT STRATEGIES

Six long-term management strategy alternatives are being analyzed in the PEIS, including the current management strategy (the "No Action alternative"), two long-term storage alternatives, two use alternatives, and a disposal alternative. The disposal alternative leads to final disposition, while the other alternatives have varying endpoints. A management strategy may include various activities such as transportation, conversion, use, storage and/or disposal. The process of constructing each of these management strategy alternatives entailed the systematic combination of selected *options* for the various activities, which formed the logical building blocks for the alternatives, as well as the basis for the organization of this document.

To analyze the costs of a given alternative, the costs of each option for activities composing that alternative were evaluated. In cases where different options were available to implement a particular alternative, the analysis considered several options. After all costs for the options composing a particular alternative were defined, the costs were summed to yield a total cost for the alternative.

2.1 Categories of Options

The following option categories are considered in this report:

- Continued cylinder storage at current sites
- Transportation
- Conversion
- Storage
- Manufacture and use
- Disposal

An option category designates a major activity in a management strategy which can be accomplished in various different ways. Each of the following discussions includes a brief examination of the options within that category, along with descriptions of specific activities or requirements associated with each option and reasons for its consideration in particular contexts. With the exception of continued cylinder storage at current sites, the technical data are found in the *Engineering Analysis Report* (Dubrin et al. 1997). Continued storage activities are described in other programmatic documents, identified in Section 2.1.1.

Facilities for the conversion, manufacture, storage, disposal, or transfer of depleted UF_6 are assumed to be constructed and operated at a generic green field site. For purposes of analysis, a period of 20 years from the onset of operations is assumed to disposition the entire depleted uranium stockpile (about 560,000 metric tons [MT] of UF_6 in 46,422 cylinders). This corresponds to an annual throughput rate of 28,000 MT of UF_6 or about 19,000 MT of depleted uranium.

2.1.1 Continued Cylinder Storage at Current Sites

Continued cylinder storage refers to the activities associated with the present approach to storing depleted UF_6 at the K-25 site at Oak Ridge, the Paducah site, and the Portsmouth site. Storage of depleted UF_6 is included under all alternative management strategies considered, the main difference being the *duration* of the storage period. In the "No Action" alternative, all of the cylinders remain in storage indefinitely. In the "action" alternatives, the cylinder inventory declines at five percent (5%) per year beginning in 2009.

The surveillance and maintenance activities that would be undertaken from now until September 30, 2002, are described in detail in the *UF_6 Cylinder Program Management Plan* (CPMP) that was submitted to the Defense Nuclear Facilities Safety Board in July 1996 (LMES 1996). Surveillance and maintenance activities are expected to continue beyond fiscal year 2002, but the scope of the CPMP was limited. Assumptions were developed to estimate the impacts and cost of continued storage because the assessment period for the draft PEIS and cost analysis extends to 2040. In developing these assumptions, it was recognized that the details of the activities actually undertaken in the future may differ from those described in the CPMP due to unexpected field conditions or budgetary constraints. A memo by Joe W. Parks, Assistant Manager for Enrichment Facilities, DOE Oak Ridge Operations Office (Parks 1997), documents assumptions for evaluating continued cylinder management activities for the No Action alternative.

The Parks memo was used as follows to develop the cost estimates for the alternatives considered in this report:

<u>No Action Alternative</u>

1999-2039	Continued cylinder storage activities as described in Parks memo

<u>Action Alternatives</u>

1999-2008	Continued cylinder storage activities as described in Parks memo
2009-2029	Continued storage of cylinders awaiting conversion or storage at another location (inventory declining 5% per year). Annual inspections (visual and ultrasonic) and valve monitoring/maintenance activities and cylinder breaches, as described in the Parks memo, decline proportionally to the reducing inventory. Repainting of the inventory would occur every ten years until 2019, when cylinders would be removed within the 10-year paint life.

The activities supporting continued cylinder storage analyzed in this document include the following:

- Routine visual and ultrasonic inspections of cylinders
- Cylinder painting
- Cylinder valve monitoring and maintenance
- General storage yard and equipment maintenance
- Yard reconstruction to improve storage conditions

- New storage yard construction
- Relocation of cylinders to new yards or to improve access for inspections
- Repair (patch welding) and contents transfer for breached cylinders
- Data tracking, systems planning and execution, and conduct of operations

The total inventory of 46,422 depleted UF_6 cylinders is currently stored as follows: 28,351 cylinders (about 60%) are stored in 13 yards at the Paducah site, 13,388 cylinders (about 30%) are stored in two yards at the Portsmouth site, and 4,683 cylinders (about 10%) are stored in three yards at the K-25 site. An intensive effort is ongoing to improve yard storage conditions. This effort includes (1) relocation of cylinders which are too close to one another to allow for adequate inspections and (2) construction of new storage yards or reconstruction of existing storage yards to provide a stabilized concrete base and monitored drainage for the cylinder storage areas. The costs for reconstruction of four Paducah yards, construction of a new yard at the K-25 site, and relocation of about 19,000 cylinders at Paducah and all the cylinders at K-25 are included in this report.

Most cylinders are inspected every four years for evidence of damage or accelerated corrosion. Annual inspections are required for cylinders that have been stored previously in substandard conditions and/or show areas of heavy pitting or corrosion (about 25 percent of the cylinder population). In addition to these routine inspections, ultrasonic testing inspections are currently conducted on some of the relocated cylinders. The ultrasonic testing is a nondestructive method to measure the wall thickness of cylinders. Valve monitoring and maintenance are also conducted for cylinders that exhibit discoloration of the valve or surrounding area during routine inspections. Leaking valves are replaced in the field.

For the No Action alternative, the frequency of routine inspections and valve monitoring is assumed to remain constant through 2039. Ultrasonic testing is assumed to be conducted annually for 10% of relocated cylinders; after relocation activities are finished, around the year 2003, 10% of the cylinders painted each year are assumed to receive ultrasonic testing inspections. For the action alternatives, the frequency of inspections is assumed to decrease with decreasing cylinder inventory from 2009 to 2029.

Cylinder painting will be employed at the three sites to reduce cylinder corrosion. The paint currently planned for use is assumed to have a lifetime of 10 years. Although repainting may not actually be required every 10 years, or budgetary constraints may preclude painting every 10 years, the continued cylinder storage analysis under the No Action alternative assumes a 10-year cycle for painting. Activities associated with breached cylinders are also assessed.

2.1.2 Transportation

Transportation involves the movement of materials among the facilities that play a role in the various alternative management strategies. With the exception of the No Action alternative, transportation occurs under each alternative, in some cases representing two or three separate steps in the process of managing depleted UF_6. Two modes — truck and rail —are considered. The following elements are included in transportation:

- Preparation of depleted UF_6 cylinders for shipment

- Transport of all forms of depleted uranium (i.e., UF_6 from the current storage sites; U_3O_8, UO_2, and U metal from conversion facilities; and uranium shields from manufacturing facilities)

- Cylinder treatment (i.e., cleaning the emptied cylinders to remove the depleted UF_6 heel, crushing the cleaned cylinders, and transporting the crushed cylinders to a DOE scrap yard)

Preparation for shipment cost refers to the cost associated with the activities required to prepare depleted UF_6 cylinders for transportation from the three current storage sites. Cylinder preparation would be required for alternatives that involve transport of cylinders to a conversion facility or a long-term storage site. The draft PEIS assumes that all alternatives except "No Action" may require transport — that is, neither long-term storage nor conversion would occur at the current storage sites. Actual siting of facilities will be considered during Phase II of the depleted UF_6 Management Program. Preparation of cylinders for shipment would occur at each of the sites currently storing depleted UF_6.

Although the cylinders currently used for storing depleted UF_6 were designed and built to meet U.S. Department of Transportation (DOT) requirements for shipment, some of the cylinders no longer meet those requirements. Review of Title 49 of the Code of Federal Regulations (CFR), the American National Standards Institute's ANSI N14.1, and the U.S. Enrichment Corporation's USEC-651, along with other documents, has helped identify three categories of cylinder problems: overpressured, overfilled, and substandard. Overpressured cylinders do not meet the requirement that they be shipped at subatmospheric pressures. Overfilled cylinders contain an inventory of UF_6 which exceeds allowable fill limits for shipping. Substandard cylinders do not meet the "strong, tight" requirements for shipment; substandard cylinders include those having corrosion sufficient for the wall thickness to be below allowable minimums, damaged cylinders, and cylinders with plug or valve threading problems or other nonconformances that prevent shipment "as-is."

Cylinders that meet DOT shipment requirements would require no special preparation and could be shipped whenever desired. Depleted UF_6 in cylinders that no longer meet DOT requirements would be prepared for shipment in one of two ways:

- The placement of the nonconforming cylinder in a *cylinder overcontainer* — a protective metal container slightly larger than the cylinder itself and designed to meet all DOT shipment requirements; or

- The transfer of depleted UF_6 from cylinders that no longer meet DOT requirements to new cylinders which do meet these requirements, with the transfer to occur at the storage site in a new facility designed specifically for this activity.

The second element of the transportation category of options, transport, includes costs for loading, shipping, and unloading activities. Loading/unloading and trip costs ($/kilometer [km]) were considered to be dependent upon mode (i.e., truck or rail), material packaging, and density. These dependencies were the same, regardless of the chemical form of the cargo. For example, transport of UF_6 was assumed to cost the same per railcar per kilometer as transport of U_3O_8, the only difference being the amount of material in a load.

The final element of the transportation category of options is treatment and transport of emptied cylinders. Most of the alternatives being considered involve removing the depleted

UF_6 from the cylinders and converting it to another form. After the cylinders are emptied, they would be washed to remove the residual heel of depleted UF_6. It is assumed that the cleaned cylinders would be crushed and then transported to the gaseous diffusion plant sites, where they would become part of the scrap metal inventory. Disposition of the emptied cylinders (46,422) and the residual "heel" of depleted UF_6 is addressed under cylinder treatment (see Section 4.1.2).

2.1.3 Conversion

Conversion of the depleted UF_6 to another chemical form is required for most management strategy alternatives. The following conversion options are considered:

- Conversion to triuranium octaoxide (U_3O_8)
- Conversion to uranium dioxide (UO_2)
- Conversion to metallic uranium

Due to their high chemical stability and low solubility, uranium oxides in general are presently the favored forms for the storage and disposal alternatives. High density UO_2 and uranium metal are the preferred forms for spent nuclear fuel radiation shielding applications due to their efficacy in gamma ray attenuation. It is assumed that the entire inventory of depleted UF_6 could be converted over a 20-year period at a single industrial plant built for and dedicated to this task. Two different processes for the conversion to U_3O_8, three different processes for the conversion to UO_2, and two different processes for the conversion to metal are considered.

The Engineering Analysis Project developed two suboptions for the dry conversion of UF_6 to U_3O_8. The first process upgrades the concentrated hydrogen fluoride (HF) by-product to anhydrous HF (AHF < 1% H_2O). In the second process, the acid would be neutralized with lime to produce calcium fluoride (CaF_2).

The conversion of UF_6 to dense UO_2 is industrially practiced in the nuclear fuel fabrication industry. By either a "wet" or a "dry" process, the UF_6 is converted to a low-density UO_2 powder under controlled conditions to assure suitable powder morphology for sintering to high density for use as power reactor fuel pellets. Three suboptions were developed in the Engineering Analysis Project for the conversion of UF_6 to UO_2. A generic industrial dry process with conversion (similar to that used for U_3O_8) followed by conventional pelletizing and sintering to produce centimeter-sized pellets is the basis for the first two suboptions. The first suboption upgrades the concentrated HF to AHF (< 1% H_2O). The second suboption neutralizes the HF to CaF_2 for sale. The third suboption, a wet process, is based on small scale studies and is referred to as the gelation process.

As described above, it is assumed that the AHF and CaF_2 conversion products are of sufficient purity to be sold for unrestricted usage. Vulnerabilities associated with this assumption are addressed in Section 6.3.1.

Two metallothermic reduction routes (batch and continuous) for the production of uranium metal were analyzed. Both processes have the same chemistry: the magnesium metal (Mg) reduction of uranium tetrafluoride (UF_4) to produce uranium metal and a magnesium fluoride (MgF_2) by-product slag. The UF_4 required for either process would be generated by the hydrogen (H_2) reduction of depleted UF_6 (a standard industrial process), producing AHF as the by-product. The standard industrial process for over 50 years has been the batch metallothermic reduction process. The MgF_2 by-product slag resulting from this process is contaminated with appreciable quantities of uranium. Without further treatment, the slag must be disposed of as a low-level waste (LLW). With the rising cost for LLW disposal, disposal has become a significant fraction of the total cost for producing uranium metal. For the batch metallothermic suboption, an acid leaching step to reduce the uranium content in the slag and potentially enable it to be disposed in a sanitary landfill is analyzed. An exemption would be required since the uranium activity in the treated slag would still be large compared to that in typical soils.

The other suboption analyzed in depth is the continuous metallothermic reduction process, which is currently under development. The initial expectation is that the level of uranium contamination in the MgF_2 by-product would be sufficiently low that a post-treatment step such as the acid leaching step used in the batch metallothermic process would not be necessary. Nevertheless, an exemption for disposal in a sanitary landfill would be required because of the small amount of remaining uranium. Process vulnerabilities associated with metal conversion options are further discussed in Section 6.3.2.

2.1.4 Long-Term Storage

Two alternatives analyzed involve long-term storage. Emplacement in the storage facility would occur over 20 years at a newly constructed consolidated facility and the facility would be monitored thereafter. In the engineering analysis, storage options are defined by the type of storage facility, and suboptions are defined by the chemical form in which the depleted uranium is stored. The types of storage facilities analyzed in the *Engineering Analysis Report* and the draft PEIS are (1) buildings, (2) below ground vaults, and (3) mined cavities. The three chemical forms analyzed are (1) UF_6, (2) U_3O_8, and (3) UO_2. The two long-term storage alternatives considered in the draft PEIS are storage of the depleted uranium as UF_6 and storage in an oxide form (either U_3O_8 or UO_2).

In the case of storage as U_3O_8, following conversion, the U_3O_8 would be stored in powdered form in 55-gal (208-liter [L]) drums. The drums would be placed in buildings, below ground vaults, or an underground mine for monitored storage. Compared to depleted UF_6, U_3O_8 provides greater chemical stability, although storage in the converted form may be less flexible, and therefore more costly, for potential future uses. In the case of storage as UO_2, following conversion, the UO_2 would be stored as dense microspheres (the product of the gelation process) or pellets in 30-gal (110-L) drums, with the drums placed in buildings, below ground vaults, or an underground mine. As with U_3O_8, the UO_2 form provides greater chemical stability compared to UF_6.

Long-term storage as UF_6 in the existing cylinders in either buildings or a mined cavity is also considered. Storage of UF_6 in the existing outdoor yards is addressed in Section 2.1.1.

2.1.5 Manufacture and Use

Currently, there exist several potential uses for depleted UF_6. The manufacture and use options evaluated in the *Engineering Analysis Report* and the draft PEIS focus on the use of depleted uranium to shield radiation. Due to its high density, depleted uranium, although radioactive itself, can be used to absorb the radiation from other, more highly radioactive materials. This shielding characteristic could be employed in the manufacture of casks for the spent nuclear fuel removed from DOE facilities or commercial nuclear power plants. Two alternatives involving the manufacture and use of depleted uranium for shielding are considered: uranium dioxide (DUCRETE™)[1] and uranium metal.

DUCRETE™ is similar to concrete but contains high-density UO_2 in place of conventional aggregate (typically gravel) as a tempering agent mixed with cement for shielding in spent nuclear fuel (SNF) storage containers. Due to the high density of UO_2, achieving a particular level of radiation shielding using DUCRETE™ requires less than half the thickness of concrete. Such a dramatic reduction in shielding thickness provides both weight and size advantages over casks using concrete shielding. DUCRETE™ may also be an appropriate material for overcontainers for spent nuclear fuel disposal, although this application is more speculative than the storage applications because the precise disposal requirements are not known at this time. Accordingly, the engineering analysis assumes that, after the spent nuclear fuel storage period, the empty DUCRETE™ cask would be disposed as low-level waste when the spent fuel is disposed. The cost of disposal of the DUCRETE™ casks is not included. The timing of such activities is not known but is assumed to be beyond 2040.

The second use alternative involves using depleted uranium as the metal in the manufacture of annular shields for a multipurpose unit system. The multipurpose unit concept is a spent nuclear fuel package that, once loaded at the reactor, provides confinement of spent nuclear fuel assemblies during storage, transportation, and disposal. In this approach, the depleted uranium is disposed of with the spent nuclear fuel.

For purposes of analysis, it is assumed that (1) casks would be based on existing designs, with the uranium shielding material enclosed between stainless steel (or equivalent) shells; and (2) the shielded casks would be produced over a period of 20 years at a central stand-alone industrial plant, transported to commercial reactors, and loaded with spent nuclear fuel.

2.1.6 Disposal

Disposal refers to the emplacement of a material in a manner which ensures isolation for the indefinite future. Disposal is considered permanent, with no intent to retrieve the material for future use. The disposal options considered in the *Engineering Analysis Report* and PEIS involve conversion of the UF_6 and disposal as an oxide — either U_3O_8 or UO_2. The U_3O_8 would be disposed of in 55-gal (208-L) drums, and the UO_2 would be disposed of in 30-gal (110-L) drums. Both bulk disposal (i.e., the U_3O_8 powder or UO_2 microspheres are placed directly into drums) and grouted disposal (i.e., the oxide forms are mixed with cement before being placed in drums) are analyzed, as well as three types of disposal facility: shallow earthen structures, below ground vaults, and an underground mine. Each disposal facility would be stand-alone and single-purpose, composed of a waste form facility and several disposal units, which would vary depending on the type of facility involved.

[1] DUCRETE is a trademark of Lockheed Martin Idaho Technologies Company and is licensed to Nuclear Metals, Inc., Concord, MA.

2.2 Definition of Alternative Management Strategies

Selected options from the six categories described in Section 2.1 can be combined to build the following long-term management strategies being considered:

- No Action alternative
- Long-term storage as UF_6 in buildings or a mined cavity
- Long-term storage as oxide in buildings, vaults, or a mined cavity
- Use as uranium dioxide in DUCRETE™ for shielding applications
- Use as uranium metal for shielding applications
- Disposal as oxide in shallow earthen structures, vaults, or mined cavity

The draft PEIS studies the potential environmental impacts of these management strategy alternatives for the 41-year period from 1999 through 2039, although the strategies could continue beyond that date. Accordingly, the *Cost Analysis Report* analyzes the same time period.

The process of combining options into a management strategy entails selecting those options that fulfill the function(s) necessary to carry out a particular alternative. It is noted that the alternatives have varying endpoints. Figure 2.1 shows the different options in alternative management strategies. (All figures are located at the end of Chapter 2.)

2.2.1 No Action

The *Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act* (40 CFR Parts 1500-1508) require that a "No Action" alternative be considered when preparing an EIS. Under the No Action alternative, DOE would continue to store its inventory of full depleted UF_6 cylinders at the three existing sites indefinitely. The activities involved in continued storage are described in Section 2.1.1 and shown in Figure 2.2. Consistent with the PEIS time frame, costs of current management activities were estimated from 1999 through 2039.

2.2.2 Long-Term Storage as UF_6

The long-term storage as UF_6 alternative involves storage of depleted UF_6 in its current chemical form until 2040. This alternative combines options from four categories, including a transportation step to move the material from its current location to a long-term storage location.

- *Continued storage* as depleted UF_6 in the current yards from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year from 2009 to 2029 until it is gone;
- *Cylinder preparation* for shipment from 2009 to 2029;
- *Transportation* as UF_6 to a consolidated storage facility from 2009 to 2029;

- *Long-term storage* as depleted UF_6 in buildings or a mined cavity from 2009 to 2040, with the amount of depleted UF_6 in storage increasing by 5% per year until all the depleted uranium is stored at a consolidated storage facility by 2029.

Under this alternative, continued storage at the current sites would occur through 2008. In the ensuing 20-year period, from 2009 until 2029, cylinder preparation for shipment, transportation to the long-term storage site, and placement in the long-term storage facility would occur. As the amount of depleted UF_6 in current storage conditions declines over this two-decade period, the amount of depleted UF_6 in long-term storage increases. Once all of the cylinders have been shipped (2029), the long-term storage facility would enter a maintenance and monitoring mode until 2040. No decision has yet been made regarding what will happen to the stored UF_6 after 2040. Long-term storage as UF_6 is shown in Figure 2.3.

2.2.3 Long-Term Storage as Uranium Oxide

The long-term storage as uranium oxide alternative considers long-term storage of depleted uranium after it has been converted to either U_3O_8 or UO_2. It is assumed that both the conversion process and long-term storage would occur at locations other than the sites presently used for depleted UF_6 storage.

The combination of options making up the long-term storage as oxide alternative fall into seven different steps, two of which are transportation:

- *Continued storage* as depleted UF_6 in the current yards from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year beginning in 2009 until it is gone in 2029;
- *Cylinder preparation* for shipment from 2009 to 2029;
- *Transportation* as UF_6 from 2009 to 2029;
- *Conversion* to oxide from 2009 to 2029;
- *Transportation* as oxide from 2009 to 2029;
- *Cylinder treatment* from 2009 to 2029;
- *Long-term storage* as oxide in a building, vault, or mined cavity from 2009 to 2040, with the amount of oxide in storage increasing by 5% per year until all the depleted uranium is stored in this form by 2029.

Once again, continued storage persists through 2029. Most of the activity under this alternative would occur in the period beginning in 2009 and continuing for 20 years: cylinders would be prepared for transportation and transported to a conversion facility; the depleted UF_6 would be converted to oxide; and the oxide would be moved to a long-term storage facility. The inverse, complementary relationship between current storage and long-term storage also persists, with the former declining as the latter increases with the transfer of material from the current sites to a long-term storage facility. Once all of the material has been shipped, the long-term storage facility would enter a maintenance and monitoring mode until 2040. Long-term storage as uranium oxide is shown in Figure 2.4.

2.2.4 Use as Uranium Dioxide in DUCRETE™ for Shielding Applications

One of the two use alternatives considered in the *Engineering Analysis Report* and the draft PEIS involves using depleted uranium to make a radiation shielding material known as DUCRETE™. Under this alternative, UF_6 would be converted to an oxide form (UO_2), which in turn would be used to manufacture DUCRETE™ casks for storing spent nuclear fuel.

This alternative consists of the following steps:

- *Continued storage* as depleted UF_6 in the current yards from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year beginning in 2009 until it is gone in 2029;
- *Cylinder preparation* for shipment from 2009 to 2029;
- *Transportation* as UF_6 from 2009 to 2029;
- *Conversion* to UO_2 pellets from 2009 to 2029;
- *Transportation* as UO_2 from 2009 to 2029;
- *Cylinder treatment* from 2009 to 2029;
- *Manufacture* of DUCRETE™ casks from 2009 to 2029;
- *Transportation* as DUCRETE™ casks from 2009 to 2029;
- *Use* as DUCRETE™ casks beginning in 2009.

Storage as depleted UF_6 would continue to 2029. Beginning in 2009, cylinders would be prepared for transportation and transported to a conversion facility, where the depleted UF_6 would be converted to UO_2. The UO_2 would be transported to a facility that manufactures DUCRETE™ casks; the casks would be manufactured; and the finished casks would be transported to a commercial or DOE nuclear facility to be filled with spent fuel. Use would increase between 2009 and 2029 as continued storage decreases, with all of the depleted uranium in use in DUCRETE™ casks by 2029. Use as uranium dioxide in DUCRETE™ is shown in Figure 2.5.

2.2.5 Use as Uranium Metal for Shielding Applications

A second long-term management strategy for using depleted UF_6 is the use as metal alternative. Under this alternative, depleted UF_6 would be converted to metal, which in turn would be used to manufacture metal casks for spent nuclear fuel or high-level waste from commercial or DOE facilities.

The use as metal alternative consists of the following steps:

- *Continued storage* as depleted UF_6 in the current yards from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year beginning in 2009 until it is gone in 2029;
- *Cylinder preparation* for shipment from 2009 to 2029;

- *Transportation* as UF_6 from 2009 to 2029;
- *Conversion* to metal from 2009 to 2029;
- *Transportation* as metal from 2009 to 2029;
- *Cylinder treatment* from 2009 to 2029;
- *Manufacture* of metal casks from 2009 to 2029;
- *Transportation* as metal casks from 2009 to 2029;
- *Use* as metal casks beginning in 2009.

Storage as depleted UF_6 would continue to 2029. Beginning in 2009, cylinders would be prepared for transportation and transported to a conversion facility, where the depleted UF_6 would be converted to metal. The metal would be transported to a facility that manufactures metal casks; the casks would be manufactured; and the finished casks would be transported to a commercial or DOE nuclear facility to be filled with spent fuel. Use would increase between 2009 and 2029 as continued storage decreases, with all of the depleted uranium in use in metal casks by 2029. Use as uranium metal is shown in Figure 2.6.

2.2.6 Disposal as Oxide

The disposal as oxide alternative considers the disposal of depleted uranium after it has been converted to U_3O_8 or UO_2. It is assumed that both the conversion process and the disposal would occur at different locations

The combination of options making up the disposal as oxide alternative fall into seven different steps, two of which are transportation:

- *Continued storage* as depleted UF_6 in the current yards from 1999 to 2029, with the amount of depleted UF_6 in storage decreasing by 5% per year beginning in 2009 until it is gone in 2029;
- *Cylinder preparation* for shipment from 2009 to 2029;
- *Transportation* as depleted UF_6 from 2009 to 2029;
- *Conversion* to U_3O_8 or UO_2 from 2009 to 2029;
- *Transportation* as U_3O_8 or UO_2 from 2009 to 2029;
- *Cylinder treatment* from 2009 to 2029;
- Disposal as oxide from 2009 to 2040, with the amount of oxide disposed increasing by 5% per year until all depleted uranium is disposed by 2029.

Disposal as oxide is shown in Figure 2.7

Figure 2.1 Options and Alternative Management Strategies

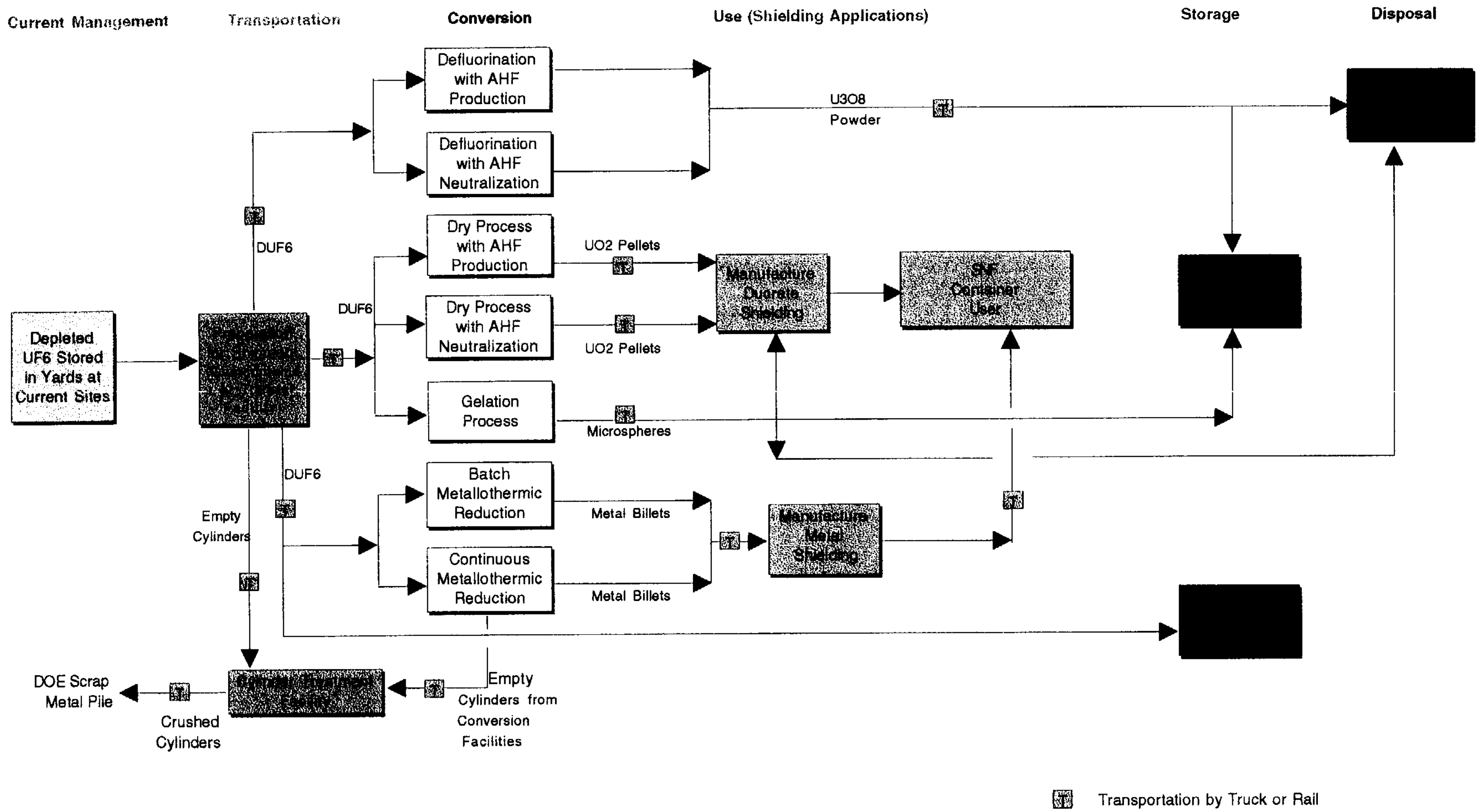


Figure 2.2 No Action Alternative - Current Management Activities Continue through 2039

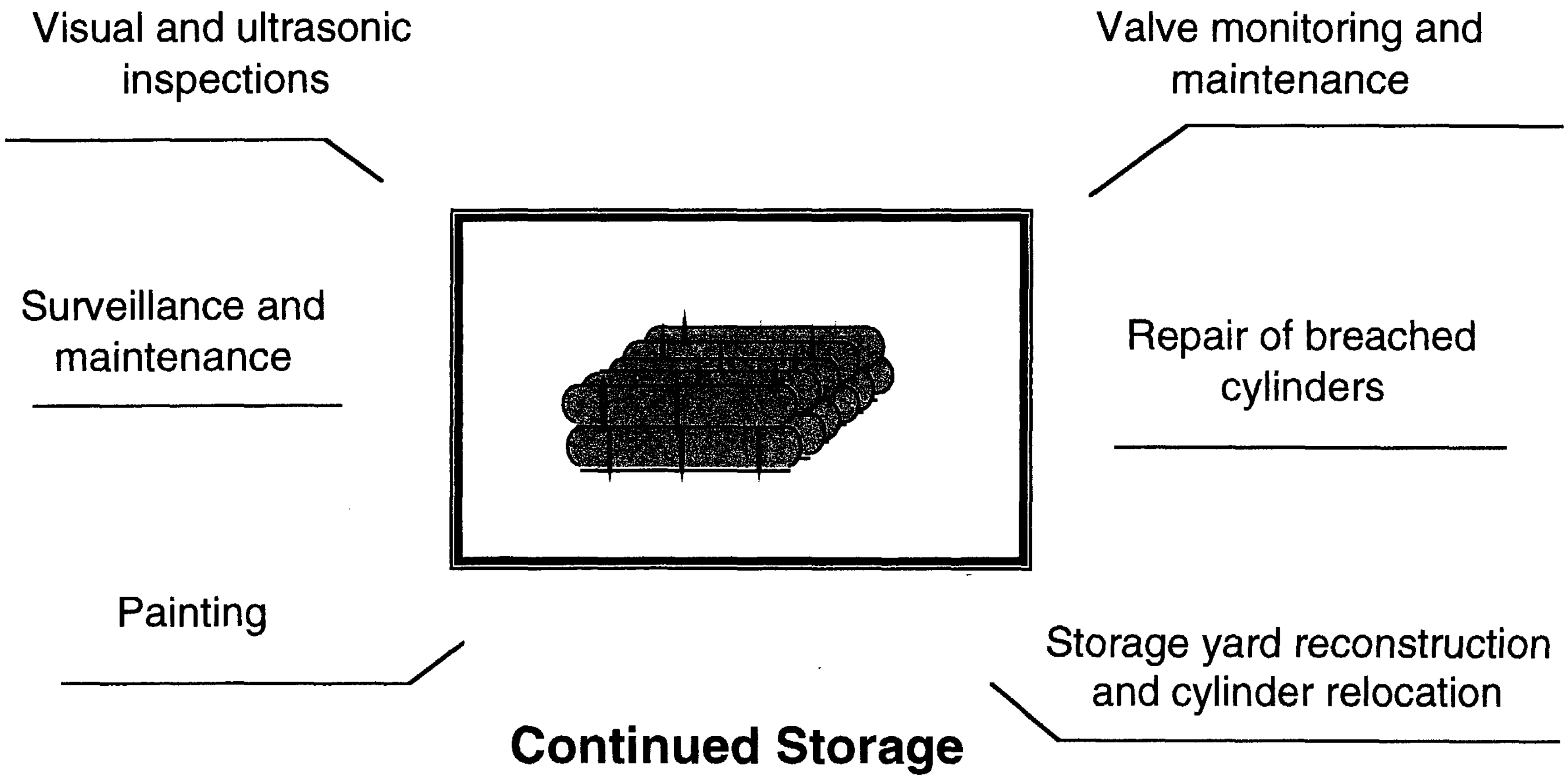


Figure 2.3 Long-Term Storage as UF_6

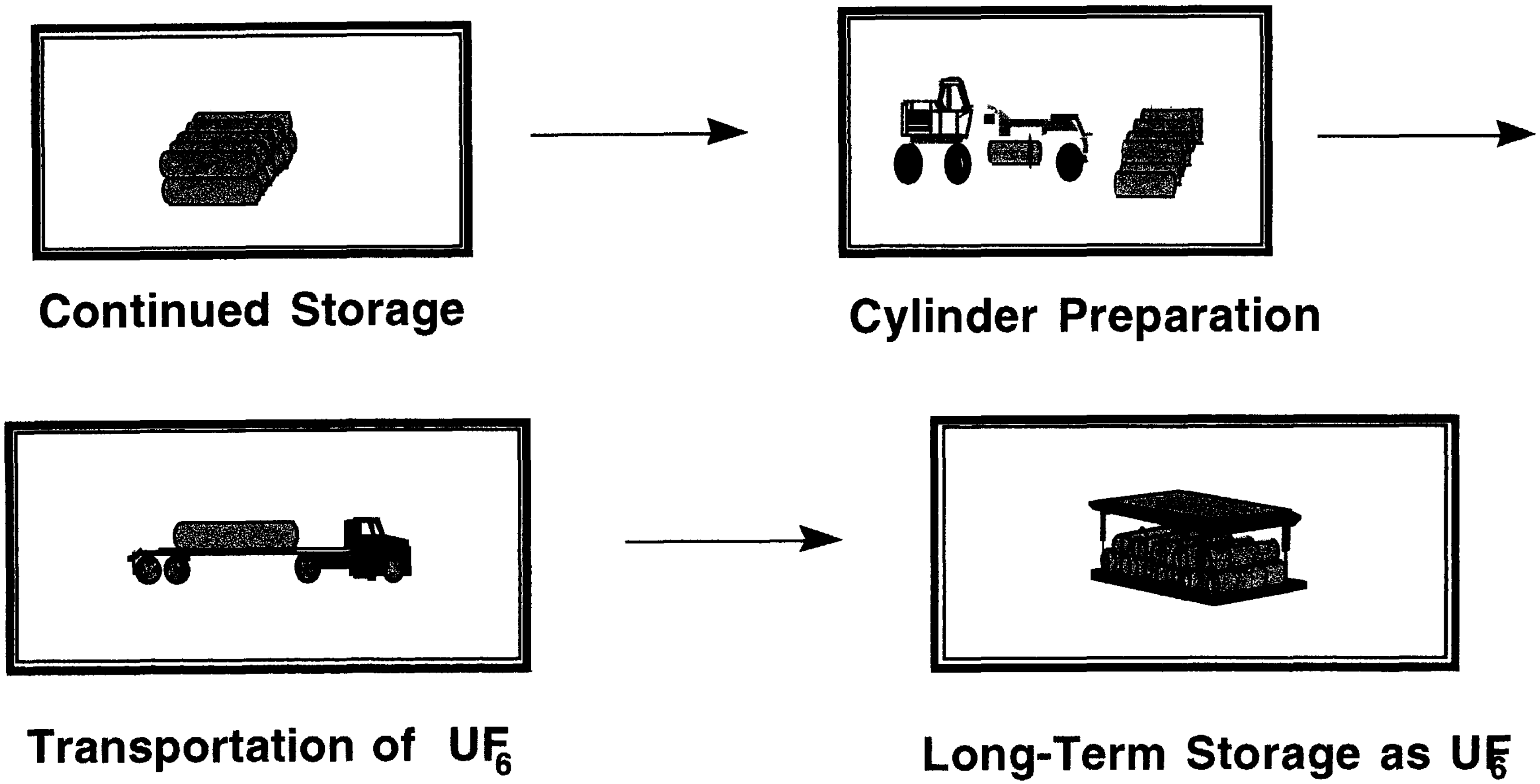


Figure 2.4 Long-Term Storage as Uranium Oxide

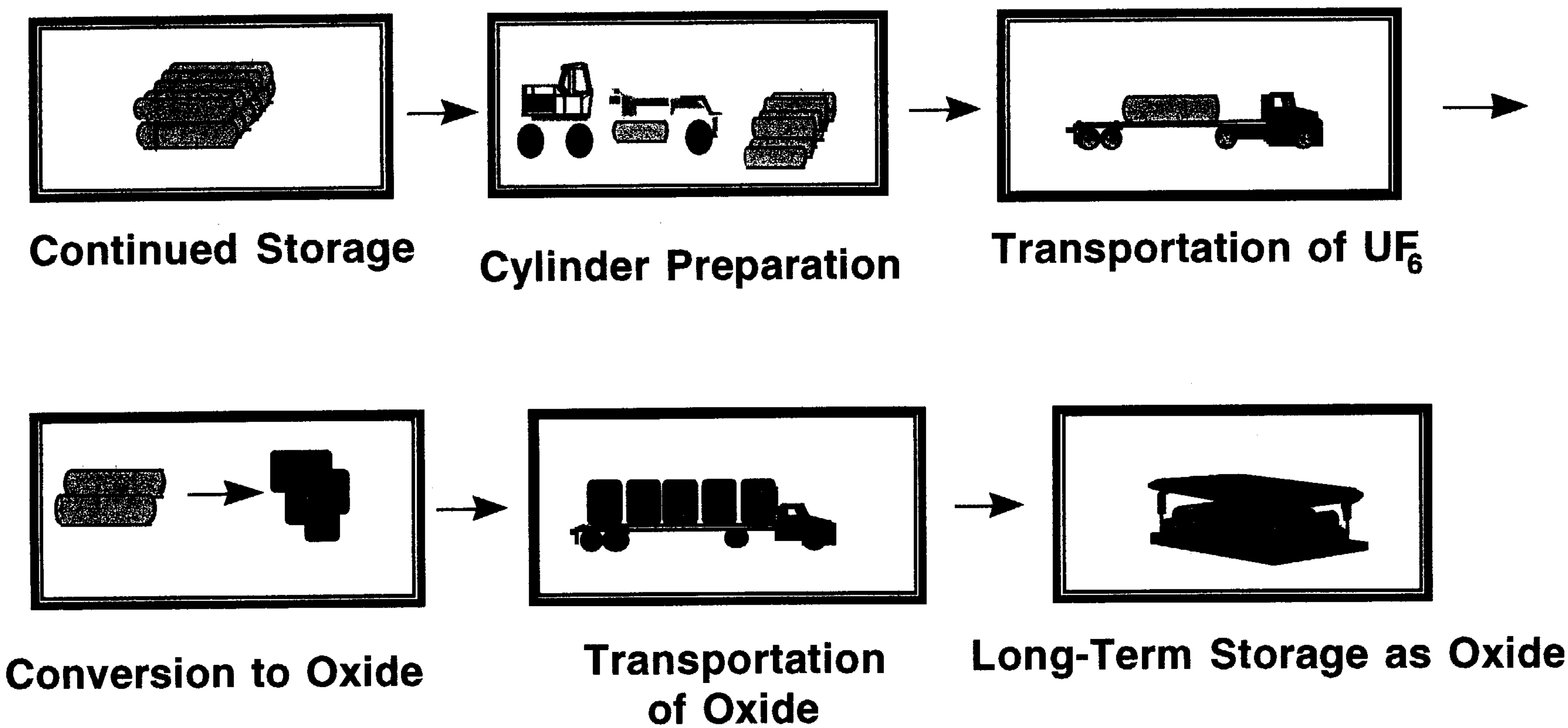


Figure 2.5 Use as Uranium Dioxide in DUCRETE™

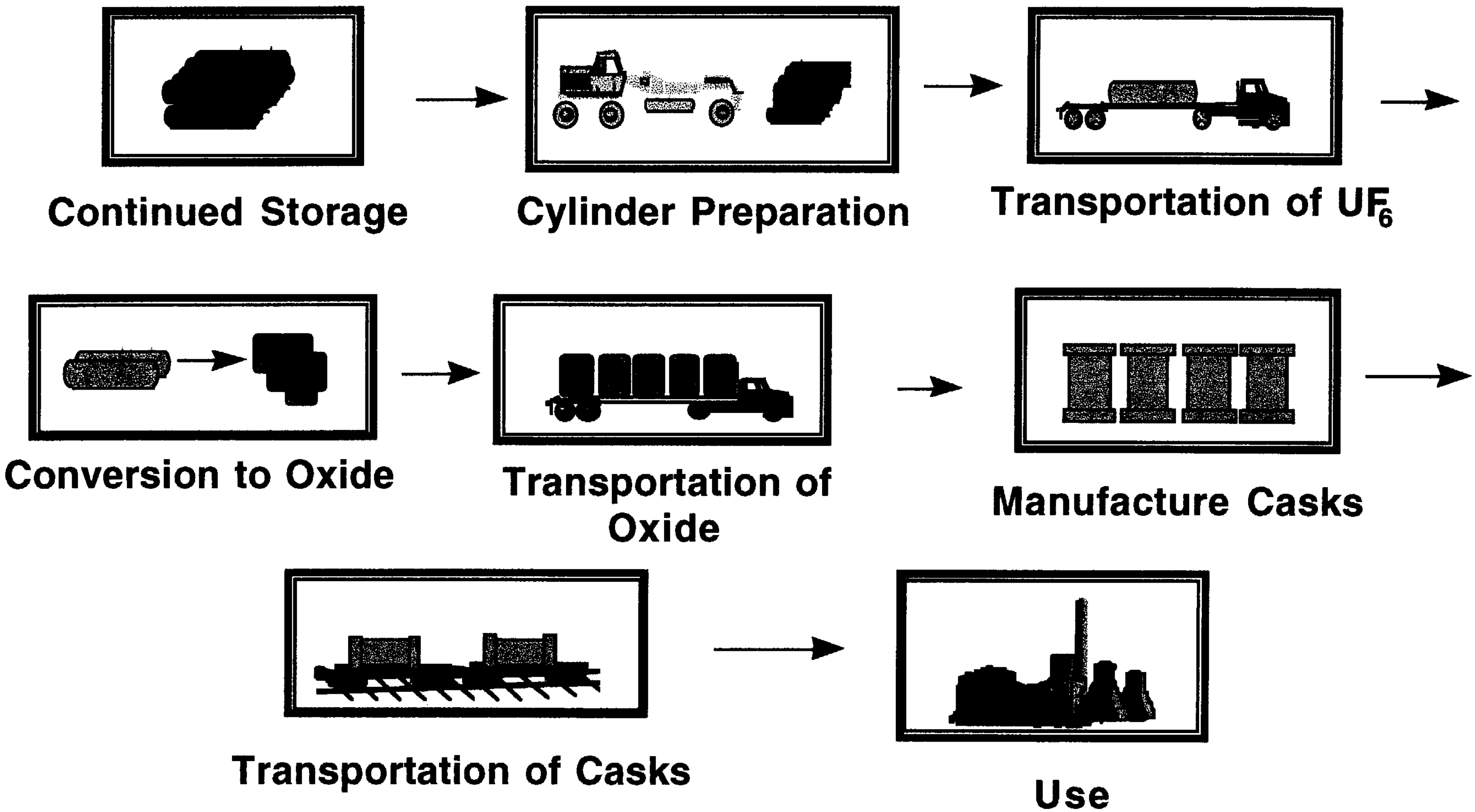


Figure 2.6 Use as Uranium Metal

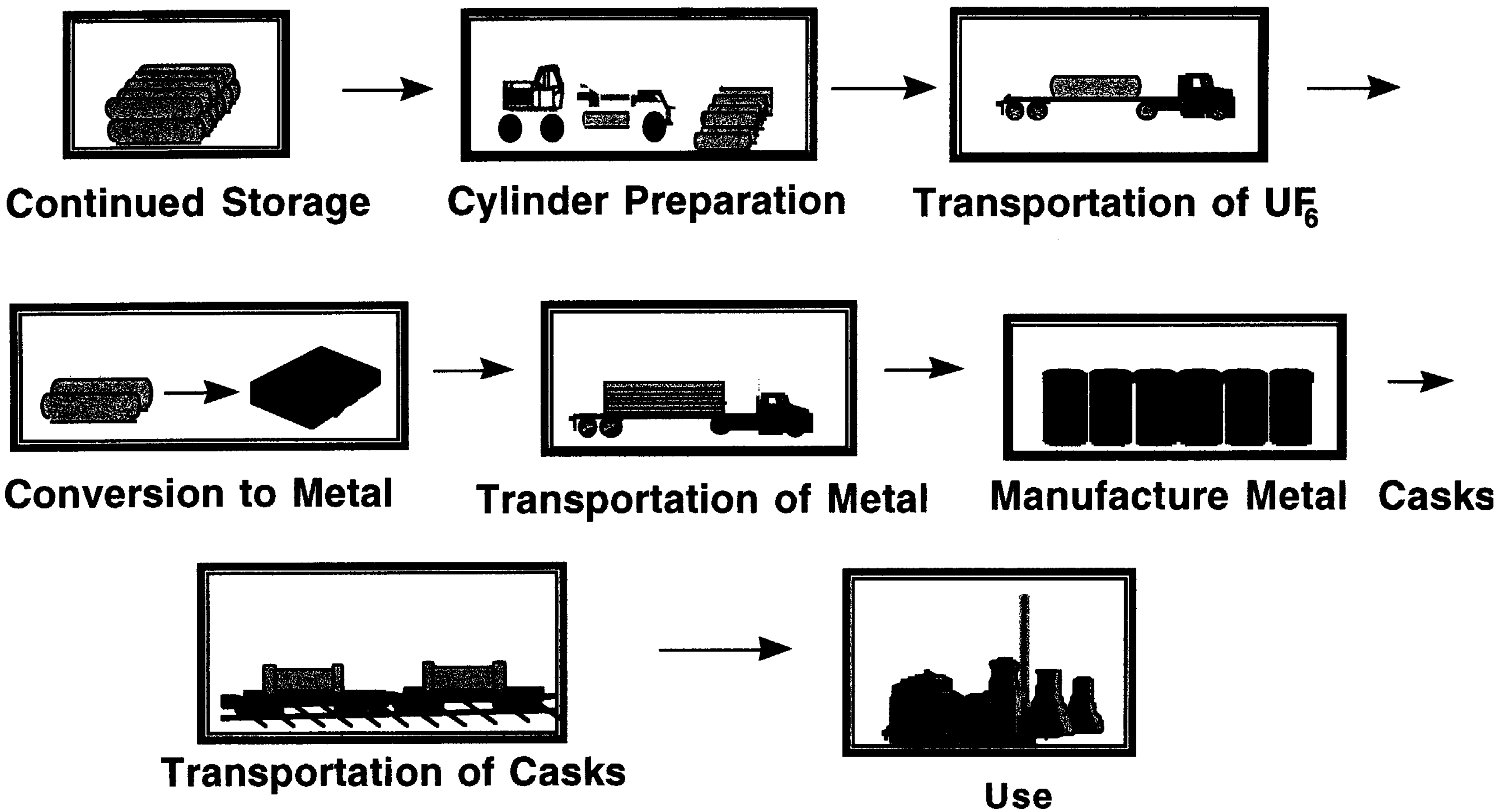
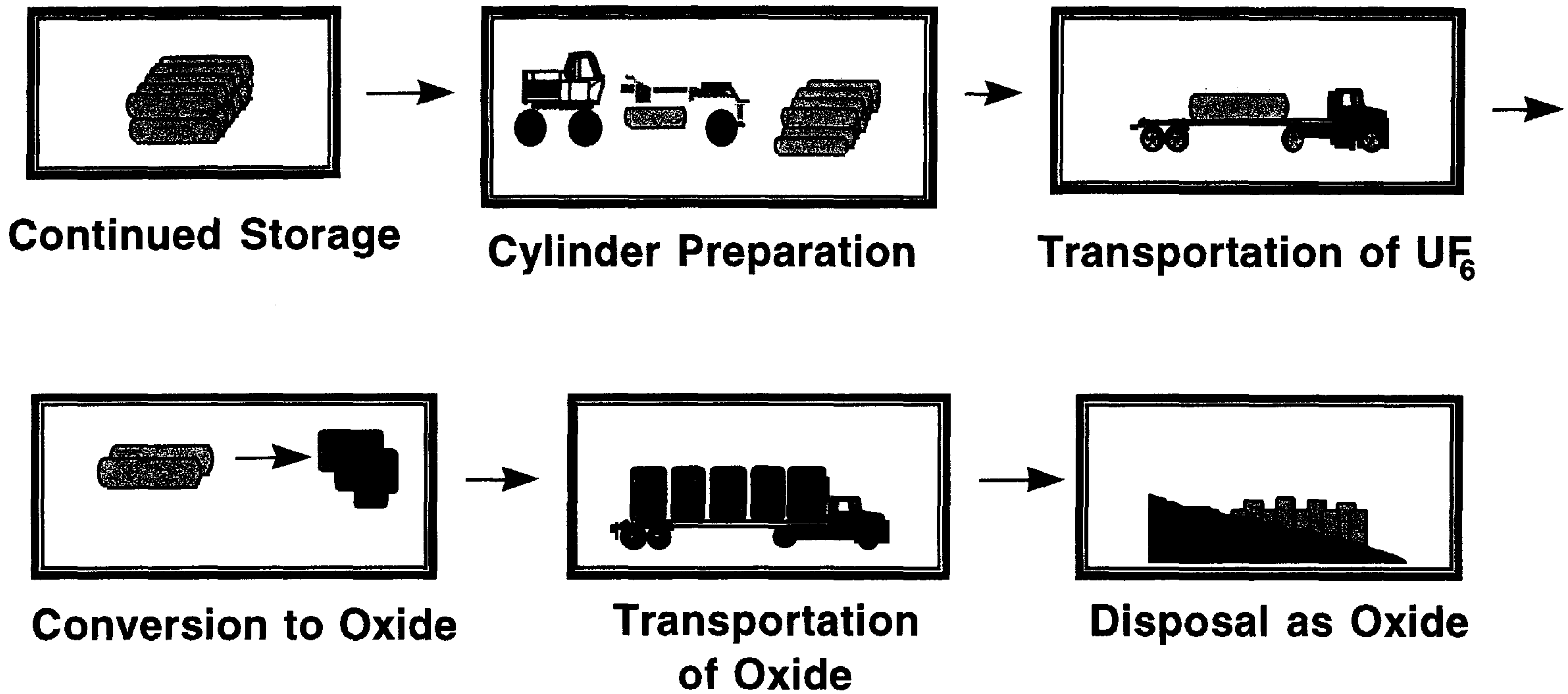


Figure 2.7 Disposal as Oxide



3. COST ESTIMATION METHODOLOGY

3.1 Approach

Costs were developed in a three-phase process. In Phase I, the costs of the primary contributors to capital and operating costs were developed. In Phase II, factors for other life-cycle costs were analyzed. These two phases were performed concurrently. In Phase III, the costs and revenues estimated in Phases I and II were integrated into a computer cost model to determine the life-cycle costs of all the management strategy alternatives being considered.

3.1.1 Cost Estimation for Primary Capital and Operations and Maintenance Costs

Each of the options described in Section 2.1 (i.e., the primary cost contributors) was analyzed as part of the Engineering Analysis Project. The costs were developed in accordance with a cost breakdown structure (CBS) paralleling the work breakdown structure (WBS) used in the Engineering Analysis Project (Lawrence Livermore National Laboratory 1996). Figure 3.1 summarizes the CBS modules and options (see Section 2.4 of the *Engineering Analysis Report* for a discussion of the methodology and the selection of options for in-depth analysis). The options which were analyzed in detail are the building blocks for the alternatives. Figure 3.2 shows the CBS at Level 6 for the U_3O_8 conversion option using the defluorination process with anhydrous HF production.

Costs were developed at least one level below that at which they are reported. These costs were reported in preliminary draft Cost Estimation Reports (CERs) that were prepared according to preset guidelines. Rather than revising the individual CERs to reflect any subsequent changes, the cost model described in Section 3.1.5 is being used to capture updates to the cost estimates.

The capital and operating costs were developed and reported year by year over the life of the project in accordance with the project schedule. A period of 20 years was assumed to disposition the entire depleted uranium stockpile (about 560,000 MT UF_6 in 46,422 cylinders). This corresponds to an annual throughput rate of 28,000 MT of UF_6, or about 19,000 MT of uranium.

A cash flow analysis was prepared to establish life-cycle costs. All costs were estimated in first quarter fiscal year 1996 dollars. In general, a scoping-level combination of vendor quotes, a factored approach based on historical cost data, and a detailed engineering (bottom-up) approach were used in estimating costs. A factored approach was used when historical data were available for cost elements, for example, for the cost per square foot of a particular type of building (e.g., Butler). The total cost was estimated using the size of the structure and the per-square-foot cost factor. A detailed engineering approach begins with a specific facility design, and, from this, estimates are made of the quantities of materials, labor, and other components required. Unit costs were applied to these estimated quantities to prepare the direct cost estimates. Additional costs were estimated using assumptions concerning the type of construction, safety and environmental regulations, production throughput, and other factors.

In Chapter 4, Cost Estimation of Options, costs are reported to the nearest $10,000, resulting in some estimates with five significant figures. A maximum of two significant figures is considered appropriate; however, rounding was reserved for the final totals (Chapter 5, Cost Estimation of Strategies) and is not used on interim results.

Figure 3.1 Cost Breakdown Structure (CBS) to Level 3

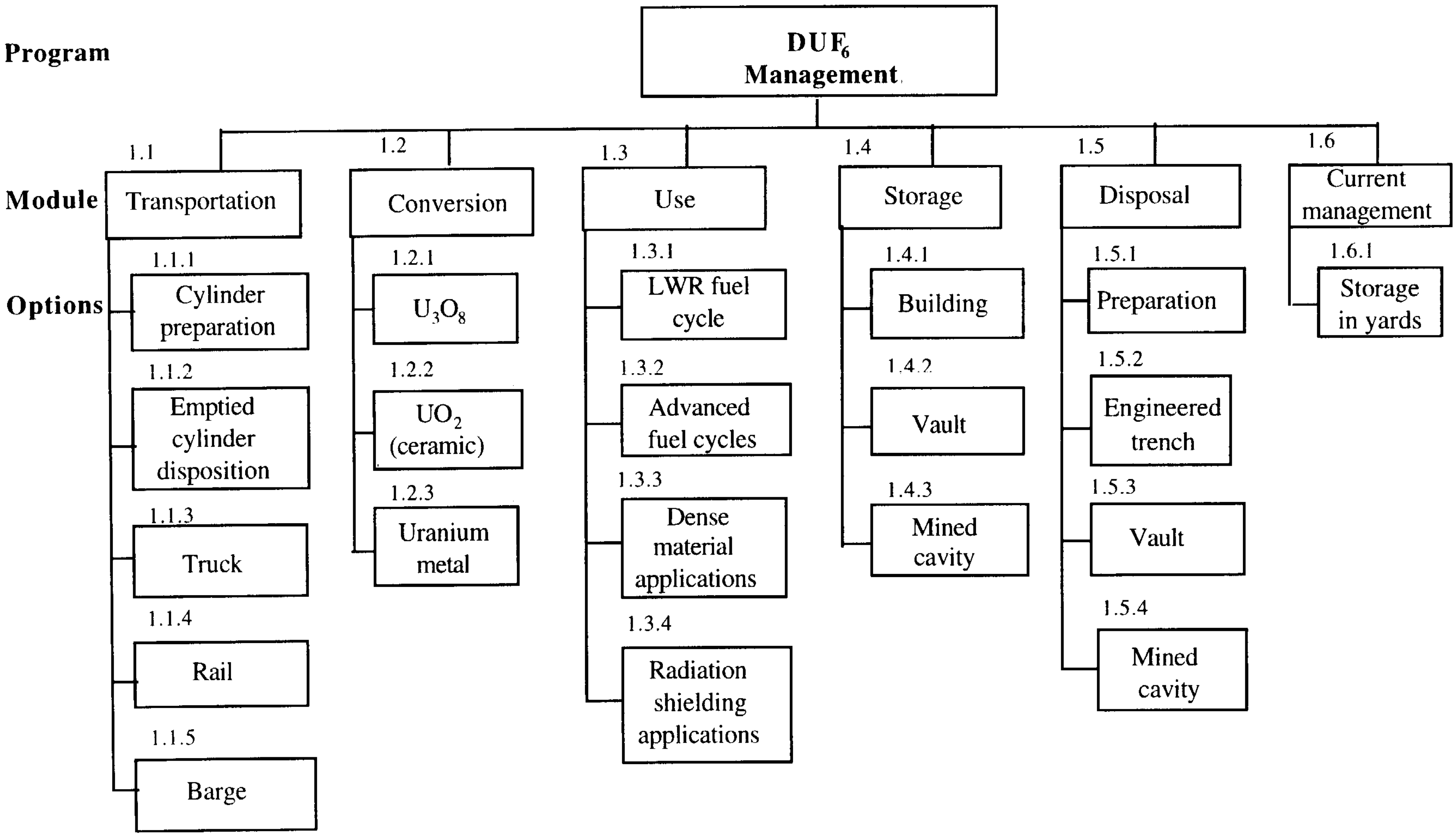
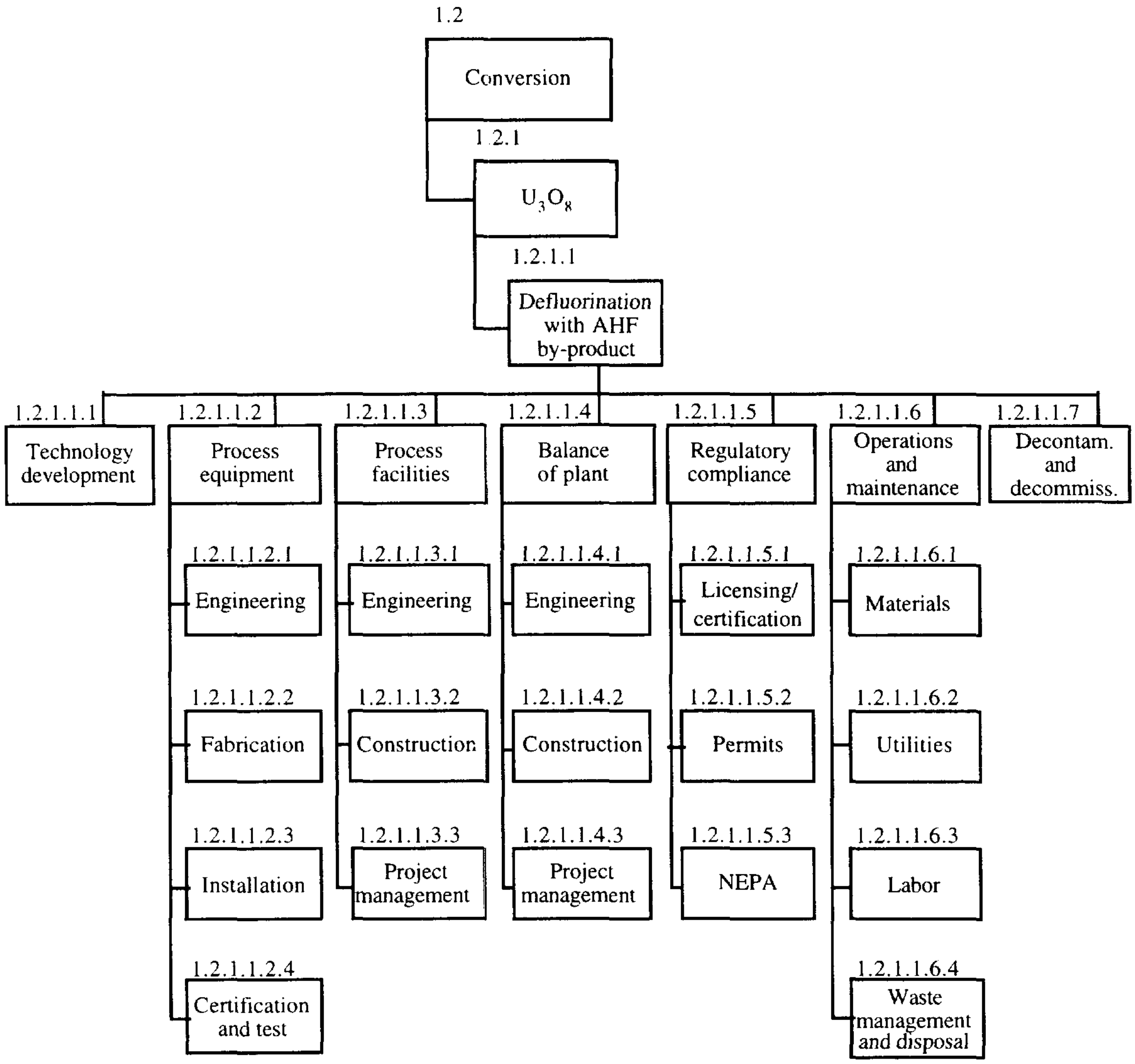


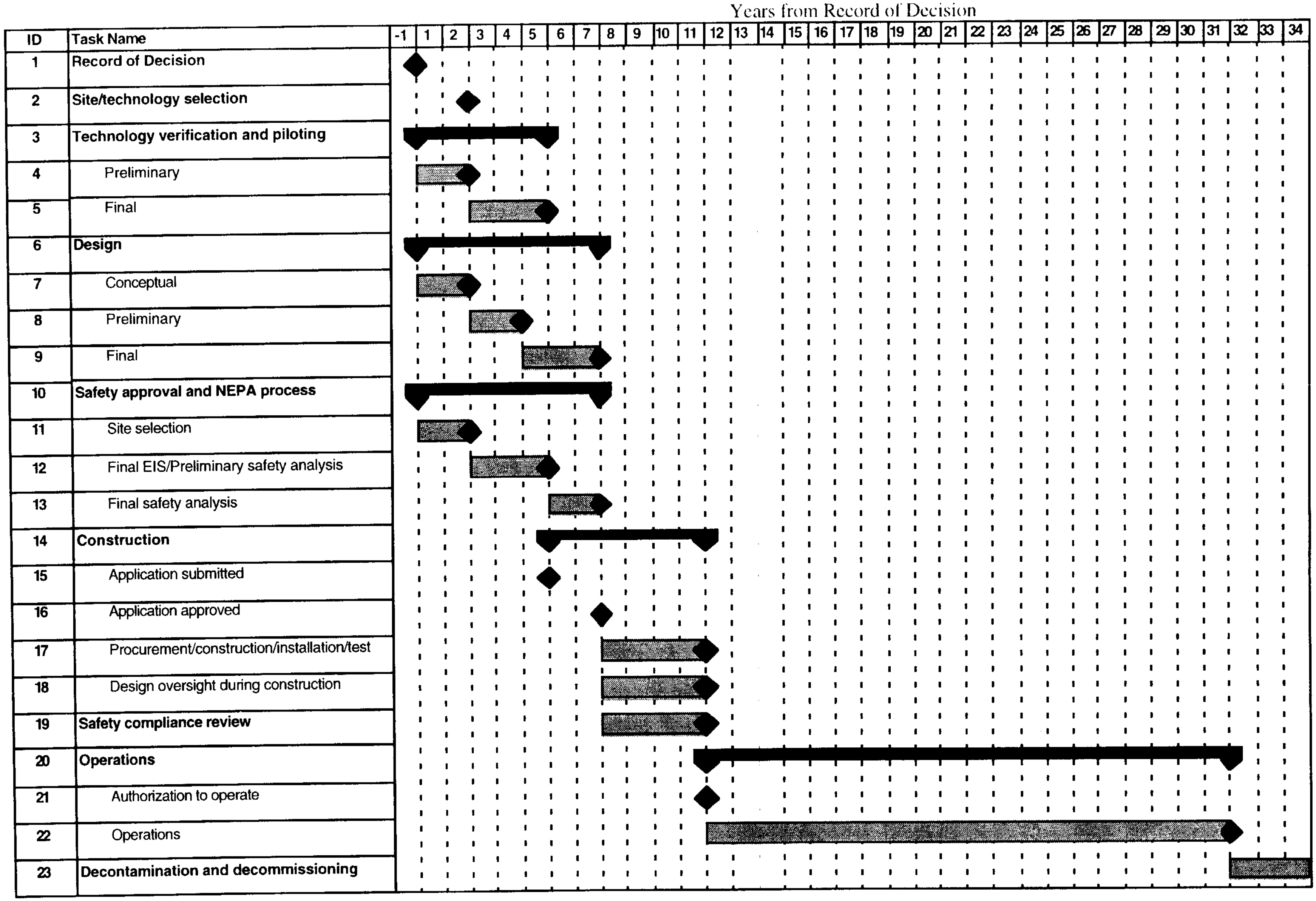
Figure 3.2 Cost Breakdown Structure (CBS) to Level 6 for Conversion to U_3O_8 Using Defluorination with Anhydrous HF Production



3.1.2 Schedule

A generic schedule was assumed for conversion (including empty cylinder treatment) and manufacturing facilities in the program. Schedules have not been differentiated for DOE or privatized facilities at this time. Beginning from the time of the Record of Decision (ROD), technology verification and piloting were assumed to take five years, including preliminary assessments. Simultaneously, design activities and the safety approval/NEPA processes would be proceeding, both of which were assumed to be completed within seven years. Site preparation, facility construction, procurement of process equipment, and testing/installation were assumed to require four years, which would have plant start-up occurring about 11 years after the ROD. Facility operation and maintenance are assumed to begin in the twelfth year and be complete at the end of the thirty-first year of the project. Decontamination and decommissioning are assumed to take three years and start immediately after 20 years of operations and maintenance. The generic schedule is shown in Figure 3.3.

Figure 3.3 Schedule



3.1.3 Basis for Financial Analysis

There are three alternatives for the ownership and operation of the conversion, manufacturing, long-term storage, and permanent disposal facilities and transportation equipment. These alternatives are government, regulated quasi-private (analogous to utility companies), and fully private. What alternative is chosen for ownership and operation has implications for basic project costs and schedules, permitting and licensing costs, facility operating requirements, capital structure of the enterprise, and sources of money and, hence, for cost of funds, profitability requirements, and taxes. These issues are beyond the scope of this *Cost Analysis Report*, whose focus is on how design requirements are translated into costs for a government enterprise.

OMB Circular A-94 Section 4 (OMB 1992) provides guidance for internal Executive branch financial analyses to be submitted to the Office of Management and Budget (OMB). In particular, it addresses federal budget preparation and analyses supporting government decision making regarding projects and programs where measurable costs and benefits extend three or more years into the future. Management of the Department of Energy's depleted UF_6 is an example of such a program. OMB Circular A-94 (Section 5) recommends use of benefit/cost analysis in the form of discounted costs and benefits. The Circular (Section 7) also requires that all costs and benefits be in initial-year dollars (that is, noninflating dollars) and that an inflation-free discount rate be used for this analysis.

In this *Cost Analysis Report*, the different depleted UF_6 management strategy alternatives are evaluated in terms of net present value of all outlays and returns, beginning with technology development and ending with facility decommissioning and decontamination.

3.1.3.1 Reference Case Return Rate

OMB Circular A-94 recommends a value of seven percent per annum (7% p.a.) for reference case analysis (Section 8b). This rate is described as approximating the marginal pretax return rate for investments in the private sector. The use of this return rate can also be supported through examination of return rates in industries similar in nature to those participating in depleted UF_6 management projects. Accordingly, the 7% p.a. value is used for reference case analyses in this *Cost Analysis Report*.

Inflation-free rates are not regularly reported in the financial and business press. A crude correction can be made by subtracting an inflation rate estimate from the reported cost of funds. The March 25, 1996, issue of *Business Week* lists the 1000 largest companies in the United States as measured by their value. Subsets of these data were examined to determine what expectation of return rate the managers and owners may have. The metric used was a pretax "return on invested capital," although other metrics are certainly possible. The results are presented below in terms of minimum, average, and maximum values:

Industry Group	Return on invested capital for 1995 (%) (Min)	Avg.	(Max)
Chemicals (5 companies)	(15.5)	22.2	(29.9)
Manufacturing (13 companies)	(1.2)	14.3	(25.8)
Paper (7 companies)	(3.4)	12.7	(21.3)
Electric utilities (9 companies)	(0)	9.0	(10.0)

Industry groups in the above table were selected as being representative of those which might be interested in participating in depleted UF_6 management strategy activities. Chemical companies have a long history of participation in the DOE missions. Studies comparing industry group characteristics have concluded that uranium enrichment has a structure similar to that of the paper industry. If the depleted UF_6 is managed as a quasi-private enterprise, the electric utility industry would seem to be a reasonable model to use for the purpose of estimating profitability expectations.

Assuming long-term stability of the U.S. economy, the future inflation rate may be in the range of 2.5-3.0% p.a. In order to estimate the inflation-free return rate, a number in this range would need to be subtracted from the return on invested capital in the preceding table. If this is done, the average inflation-free return rates range from 10-19% p.a. for private industries which might be similar in nature to those participating in depleted UF_6 management projects and 6% p.a. for a regulated industry.

It is believed that these examples support the OMB Circular A-94 recommendation of a reference case value of 7% p.a. if one remembers that 7% does not cover all businesses' requirements for return on investment. In fact, the 7% p.a. return rate seems appropriate for a licensed monopoly (such as a utility) where government regulation, not free competition, protects the consumer from overcharging.

3.1.3.2 Return Rates for Sensitivity Studies

It is important to look at the financial analysis from a sensitivity study perspective to ensure that the ranking of strategies does not depend strongly on the choice of discount rate. In Chapter 6, the sensitivity of results is tested by reporting net present values of the alternative strategies at 4% and at 15% p.a., as well as at the reference case rate of 7% p.a. The purpose of the next paragraphs is to establish the reasonableness and rationale for 4% and 15% p.a. sensitivity study return rates.

The table in Section 3.1.3.1 shows the impacts of investment risk certain industries have become accustomed to as they pursue their customary lines of endeavor. As indicated, there is a range of returns within an industry group which depends on the details of the various enterprises and the ability of the managers to forecast and prepare for the future. Additionally, not shown in the table are the temporal trends or business cycles to which several industry groups are subject and which affect year-to-year profitability. In this latter sense, profit margins for 1995 were about 25-40% better for the industry groups shown than were those of 1994.

The data in the preceding table support an upper sensitivity return rate in the neighborhood of 15% p.a. for conventional private industries which operate in a competitive market where return rates do not have to be restricted by government entities to protect consumers. The lower bound for sensitivity calculations can be derived from an assumption that depleted UF_6 management will be a government project since the material was government-generated and now is government-owned. The guidance of OMB Circular A-94 (Appendix C) is to use 3% p.a. for government projects extending for 30 years.

The business literature provides other measures of return rate expectations. Among these are the bank prime rate and U.S. Treasury bond rates. The March 13, 1997, *Wall Street Journal* quotes the following values for these metrics:

Prime rate (set 2/1/97)	8.25% p.a.
U.S. Treasury bond rate	
2 year	6.08% p.a.
5 year	6.42
10 year	6.58
30 year	6.87

The prime rate indicates a demand for an inflation-free commercial return rate of 5.25-5.75% p.a. when the investment has minimal risk. However, its use is inappropriate for the purpose of developing a lower bound return estimate where the project is postulated to be government owned and operated. For this case, U.S. Treasury bond rate data are appropriate because the government assumes all the risk. The data in the table above imply an inflation-free return rate of about 4% p.a. for a lower bound government project, where there is minimal business risk. For this analysis we have chosen the 4% p.a. figure as the lower sensitivity value.

3.1.4 Other Life-Cycle Costs

Other life-cycle costs and revenues were the subject of their own special studies. Examples include market surveys to determine the market price for the anhydrous HF and CaF_2 by-products produced from conversion (described in Section 4.2.2). An estimate of the cost of regulatory compliance was another study (described in Section 3.2.4). Cost estimates for both DOE and Nuclear Regulatory Commission (NRC) requirements under each option were estimated. The more costly DOE requirements were integrated into the computer model described in Section 3.1.5 and included in the cost estimates for each option.

3.1.5 Integration of Costs

A computer model was developed to integrate the primary capital and operating costs and other supporting costs and factors. Unit costs and facility size were used as a base, to which were added appropriate costs for installation, project management, taxes, contingency, and other factors; site preparation and utility costs; and decontamination and decommissioning costs. Cost factors and other cost assumptions described below are input variables in the cost model. As such, they may be revised as necessary.

3.2 Cost Basis

The preoperational, capital, operating, and other life-cycle costs are described in the remainder of this section. A median cost reflecting contingency based on a 50% probability of overrun and a 50% probability of underrun is reported. Stated another way, there is a 50% likelihood that the as-built costs would be either greater or less than those presented.

3.2.1 Technology Development

The cost of technology development includes the costs for verification and piloting necessary before detailed design and engineering. Design work performed prior to Title I design and funded out of the DOE operating or new owner's budget falls in this category. Usually, this work is performed by an architect/engineering (A/E) firm or by the resident engineering staff at a management and operations (M&O) contractor site. Such a design is usually the first "bottom-up" design using take-offs from drawings and equipment specifications and includes a cost estimate. Technology development is shown on the generic schedule (Figure 3.3) as technology verification and piloting during years 1-5.

Initial projections of technology development costs, including pilot scale testing, are provided in the cost tabulations found in subsequent chapters. The cost estimates were primarily based on engineering judgment, following review and ranking of the subsystem uncertainties. The focus is on relative costs. The reader is referred to Chapter 3 of the *Engineering Analysis Report for the Long-Term Management of Depleted Uranium Hexafluoride*, Rev. 2. It was implicitly assumed that the development and testing would be conducted in existing facilities capable of handling large quantities of depleted uranium and having suitable infrastructure.

Definitive engineering development costs will be established in a subsequent phase of the Depleted UF_6 Management Program.

3.2.2 Capital Costs

This section defines the terminology used in the discussion of facility capital costs, lists the components of a capital cost, and outlines the approaches used to estimate these costs.

3.2.2.1 Architect/Engineering

Architect/engineering design costs were estimated at 25% of total field cost. This includes conceptual, Title I, Title II, and Title III design and engineering.

Title I is the preliminary design and is usually the first line-item funded design effort for a facility. It includes detailed drawings, bills-of-material, and craft labor requirements. A Title I cost estimate is usually also produced. An architect/engineering firm is often used for this level of design effort. The design at this point will be site-specific. Title II design produces the final preconstruction drawings, bills-of-material, and other specifications. The same A/E firm as for Title I design is often used. Title III is engineering that takes place primarily during construction and involves verification that the Title II final design is being implemented. Inspection activities and quality assurance (QA) are included in this category.

Architectural and engineering costs are incurred during the design period shown on the generic schedule. The A/E costs for process equipment, process facilities, and balance of plant are found at CBS Level 6. Conceptual design costs are 10% of total A/E cost spread evenly over the first two years. Eighty-five percent of the remaining 90% of A/E costs

(76.5% of the total A/E cost) was allocated to preliminary (years 3-4) and final (years 5-7) design. The final 15% of the remaining 90% (13.5% of the total A/E cost) was allocated to the design oversight of construction (years 8-11)

3.2.2.2 Construction

The initial site selected for costing purposes was a hypothetical green field site in Kenosha, WI. This is the standard description for an east/west central site and is typical for electric power generation facilities, having access to water and rail transportation. It was used for the engineering analysis and establishes the basic manual labor rates and state sales tax.

Davis-Bacon manual labor rates for Kenosha, WI, the Workers Compensation Insurance rates for Tennessee, and a standard 40-hour work week were used, plus an allowance of 1% for casual overtime. If costing involved an existing or a different site, Davis-Bacon manual rates for that specific area were used. For example, labor rates at Portsmouth, OH, Paducah, KY, and Oak Ridge, TN, were used to estimate the cost of continued storage of depleted uranium hexafluoride in yards.

For process equipment cost element (CBS Level 5), capital costs for materials and tax on materials are captured under fabrication at CBS Level 6, as shown on Figure 3.2. After engineering and process equipment are subtracted, the remaining capital costs for process equipment are captured under installation at CBS Level 6. For process facilities and balance of plant (CBS Level 5), these costs are captured under construction at CBS Level 6.

Direct construction costs include the cost of craft labor, construction materials (such as concrete forms, rebar, concrete, structural steel, piping, electrical raceway and cable) and installed equipment (such as process equipment and service equipment). Costs were estimated as follows:

Cost Element	Basis, Assumption, Value Range
Major equipment:	Vendor quotes; historical data; or a factor approach based on complexity, size, mass, and technical maturity
Process support equipment:	Same as major equipment or percentage of major equipment cost, depending on the type of support equipment
Process support systems:	Actual cost or percent of major equipment cost, depending on the support system
Major facilities:	Quantity take-offs or "bottom-up" estimates or factored approach
Support facilities:	\$/square foot or \$/cubic foot, depending on the classification of the facility
Facility support systems:	\$/unit or percent of total facility cost, depending on type of facility support system
State sales tax:	Sales tax on materials (including distributable field costs on materials) - 6%

Indirect costs are distributables (general conditions), overhead, and profit. These include support to direct construction for temporary construction facilities, construction equipment, construction support, field office expenses, and craft supervision. Construction facilities include on-site offices, warehouses, shops, change rooms, construction roads, construction parking lots, etc. Construction support includes such items as construction tools and consumables, safety equipment, material handling and warehousing, and general cleanup. These costs were estimated as follows:

Distributable field (general conditions) costs:	Distributable field costs for materials are 28% of the direct labor costs. Distributable field costs for labor are 75% of the direct labor costs.
Contractor's bond:	1% of total contractor's contract value
Contractor's overhead and profit:	5% for materials and 15% for labor, taken as a percentage of both total direct costs and distributable field costs.

Initial spares are major and crucial extra equipment items purchased out of the project capital budget. These are items needed to ensure process operation in the event of the failure of a major piece of installed equipment. The nature and cost of these items are technology-dependent.

Initial spare parts:	10% of process equipment, exclusive of piping, instrumentation, and installation

3.2.2.3 Balance of Plant

The balance of plant CBS includes the costs of site improvements, utility buildings, services, and support buildings. Site improvement costs include roads, parking areas, fencing, landscaping, and railroad spurs. Support buildings include an administration building, a utility building, a site warehouse, maintenance shops, an entry control building, and sanitary and industrial waste treatment facilities.

Once a site for a facility is recommended, it must be certified that the site geology, infrastructure, and meteorology are capable of safely accommodating the facility and any wastes or emissions generated therefrom. For geologic disposition options, this can be a lengthy and expensive step. Much of the work involves environmental and geologic sampling and documentation of findings. Although no specific sites were selected during Phase I of the Depleted UF_6 Management Program, generic site selection and site qualification costs were developed.

3.2.2.4 Cost Estimating Contingencies

Engineering contingencies which reflect the level of the preconceptual designs, the engineering data available, and the experience base were determined for the various options. It was assumed that a development program would verify process feasibility, demonstrate successful equipment operation and integration, and generate engineering data for scale-up to production size equipment. These cost estimating contingencies were applied to capital costs as follows:

- Process and manufacturing facilities: 30%
- Balance of plant: 20%

- Process and manufacturing equipment: variable (~30-50%, depending on option)

The variable process and manufacturing cost estimating contingencies do not consider process feasibility or performance risk, which is described in Chapter 6 (the sensitivity analysis) of this report. In particular, factors that indicated a higher process and manufacturing contingency included (1) little or no operational experience with similar processes or equipment, (2) first-of-a-kind and custom-designed equipment, (3) uncertainty regarding the selection of materials of construction, and (4) conceptual nature of equipment or lack of good definition. Factors that indicated a lower process and manufacturing contingency included (1) industrial experience with similar processes and equipment, (2) standard unit operations with well-recognized design methods, and (3) standard or off-the-shelf equipment.

3.2.3 Capital Costs - Project Management

For government-owned facilities, DOE usually hires a construction manager (normally an A/E firm) to handle the subcontracting of craft labor and to interact with the design A/Es and equipment vendors.

Construction management:	10% of contractor's field cost after taxes
Project management:	6% of total capital costs, including both direct and indirect costs

3.2.4 Regulatory Compliance

Scoping-level estimates were developed as a separate study for the cost of permitting, licensing, and environmental documentation under both public and private ownership and operation. The following were considered:

- Atomic Energy Act/Nuclear Regulatory Commission (NRC) regulations
- Department of Energy Orders
- Clean Air Act
- National Environmental Policy Act
- Resource Conservation and Recovery Act
- Clean Water Act
- Packaging and Transportation of Radioactive Material/NRC regulations
- Hazardous Materials Transportation Act
- Safe Drinking Water Act
- Emergency Planning and Community Right-to-Know Act

Under the Atomic Energy Act, DOE Orders would apply to DOE-owned facilities while NRC regulations would apply to privately owned commercial facilities. Both costs were estimated, but only costs for regulation under DOE Orders is included in the *Cost Analysis Report* since this is the more costly set of requirements.

Regulatory compliance includes preparation of the site-specific EIS (which follows the more generic PEIS) and state, local, and federal permits related to air and water quality. Construction permits are also included in this category, which covers the legal and technical work needed to obtain the NRC license required to begin construction. Some technical work, such as safety documentation, would be performed by vendors, new owners, or national laboratories.

3.2.5 Operations and Maintenance - Materials

Operations and maintenance costs are captured at Level 5 of the CBS.

Chemical or feed costs:	Cost of consumable materials for process operations such as chemicals, cements, and additives are based on vendor quotes, *Chemical Market Reporter* magazine, or similar sources.
Facilities and equipment maintenance and spares:	4% of the total direct facility capital cost

3.2.6 Operations and Maintenance - Labor

Direct Operations Staff

This category includes salaries plus fringe benefits for those persons directly associated with operations, such as chemical operators, foremen, and technicians, plus their line supervision. Clerical and health physics support in the process area are also included here.

Number of shifts:	One, two, or three, depending on engineering design
Breakdown of staffing and cost/person-hour:	Davis-Bacon wage rates for Kenosha, WI, for nonexempt employees and current national average wage rates for exempt employees
Production rate:	Based on 20 years of operation, 28,000 MT of depleted UF_6 per year
Plant availability:	80% of operating days/year, unless engineering data reports specifically prescribe otherwise

Direct Maintenance Staff

This category includes salaries plus fringe benefits for those persons directly associated with maintenance.

Indirect Staff

This category includes salaries plus fringe benefits for other personnel needed to run the facility in a safe and environmentally compliant manner meeting all federal, state, and local regulations. Among the indirect staff would be medical personnel; engineers; research and development (R&D) staff (for post-startup, process improvement R&D); human resources personnel; fire fighters; stores clerks; travel clerks; in-house environment, safety, and health (ES&H) oversight personnel; and the secretarial pool. Some of these functions may be shared with other facilities on a DOE reservation and their costs allocated on a fair basis.

Prior to commencing normal operations, the operator of a facility (presumably an M&O contractor/owner) must become familiar with the facility processes. Technology and information transfer from vendors to the M&O contractor/owner is required. DOE Orders and NRC requirements also necessitate extensive training of M&O staff, not only on technical operations, but also on the ES&H aspects of facility operations. Start-up costs were estimated to be 65% of the first year's operating labor, incurred the year before operations begin.

Current regulatory regimes require complete documentation of operational procedures prior to facility start-up. As part of this activity, manuals for various process equipment items must be prepared, which may involve both vendors and M&O contractors/owners. The facility project office must also prove to the NRC or DOE that the facility is ready to commence operations in a safe and environmentally benign manner. Considerable time on the part of the contractor and regulatory staff may be required to prepare for and carry out these reviews.

3.2.7 Operations and Maintenance - Utilities

Utilities include annual costs for electric power, natural gas, fuel oil, water, purchased steam, telephones, and other nonelectric utilities. Utility costs depend on the location of the facility.

Utilities and services costs:	10% of total operating labor or based on current rates and power requirements, whichever is greater

3.2.8 Operations and Maintenance - Waste Management and Disposal

Depending on the characterization of wastes by engineering studies, the cost of disposal will be determined by the approaches defined below. Packaging and transportation costs will be added where applicable. Disposal costs were based on Murray (1994). The cost per unit volume for waste disposal is an input variable in the cost model and may therefore be modified.

Mixed Waste

Disposal costs for mixed (radioactive/hazardous) waste were reported in this category. A cost of $100/cubic foot was used.

Hazardous Waste

Disposal costs for hazardous waste were reported in this category. A cost of $20/cubic foot was used.

Low-Level Radioactive Waste

Waste of this type is sent to DOE sites or special burial sites covered under regional LLW compacts. The cost is typically levied on a $/cubic foot basis. A cost of $100/cubic foot was used.

Nonhazardous Waste

Nonhazardous sanitary liquid wastes generated in facilities are transferred to an on-site sanitary waste system for treatment. Nonhazardous solid waste disposal costs (e.g., CaF_2) are assumed to be $2/cubic foot.

3.2.9 Revenues

Some of the conversion processes result in marketable by-products, such as the anhydrous hydrofluoric acid (AHF) produced in the defluorination process and the calcium fluoride from the neutralization process. The use module in the engineering analysis anticipates direct use of the depleted uranium shielding forms. These products or by-products will generate revenues which partially off-set the conversion and manufacturing costs. An initial market survey was conducted to determine the size of markets for the major by-products (AHF and calcium fluoride) of the various conversion processes. Issues addressed included annual sales of product, price, growth or reduction forecast for the markets, and the capacity of the market to absorb additional supply without undue effects on price. The effect of shielding cask values is presented in Section 6.1.3, while the revenue from sale of AHF and CaF_2 is presented in Section 4.2.2.

3.2.10 Decontamination and Decommissioning (D&D)

It was assumed that a DOE M&O contractor and perhaps an A/E would shut down and decontaminate the facility and remove contaminated and junk equipment. It was assumed that facility demolition would not be required. The D&D cost includes disposal of contaminated or junked equipment at licensed disposal sites.

Decontamination and decommissioning:	10% of the total costs for process equipment, process facilities, and balance of plant (i.e., the plant capital cost)

This estimate is based on historic and projected D&D costs for facilities with similar complexity, size, and hazardous waste characteristics.

3.2.11 Transportation

All costs for transportation of depleted uranium were tabulated. An engineering cost analysis of transportation alternatives was conducted and a submodel developed to assess the cost per unit quantity per unit distance traveled and the loading/unloading operation performed.

3.2.12 Exclusions

The following items have been excluded from the estimates during Phase I, but may be included during Phase II of the Program, when there is a basis for defining these costs:

- Fees earned by M&O contractors
- Royalties to third parties
- Payments in lieu of property taxes
- DOE oversight costs
- Cost of land

Land requirements for each option were estimated in the *Engineering Analysis Report*. The cost of land was excluded, however, because land prices are highly dependent upon location, which will be determined in a later phase of the Program. In addition, it would neither discriminate between alternatives nor significantly affect the total cost of an alternative, as illustrated in the following paragraph.

The estimated land area required for the conversion options ranges from about 13 to 20 acres. Assuming that land in an industrial area costs $5,000 per acre, this would add up to $100,000 (a few hundredths of a percent) to the cost of implementing a conversion option. Estimated land requirements are greater for the use, storage, and disposal options than for the conversion options. Shielding fabrication facilities occupying 90 acres would add about $450,000 (again, a few hundredths of a percent) to the total cost. Land requirements for storage facilities are estimated to range from 74 acres for mined cavity storage of UO_2 to 212 acres for vault storage of U_3O_8 with corresponding land costs of $370,000 to $1,060,000, based on a unit cost of $5,000 per acre. Inclusion of the cost of land would add less than one-half of one percent to the total cost of each option and would be insignificant when comparing storage options (e.g., building, vault, or mined cavity). A similar comparison may be made for disposal options, where the greatest land requirement is for disposal of grouted U_3O_8 in a mined cavity (1141 acres). Including the cost of land for this option would increase the cost by less than one-half of one percent.

4. COST ESTIMATION OF OPTIONS

All costs reported in this document are median costs (50% probability of overrun and 50% probability of underrun) and are given in millions of first-quarter 1996 dollars discounted to the beginning of the project. The discount rate used for the reference case was 7% p.a.

4.1 Transportation

Transportation costs include the following elements:

- Preparation of depleted UF_6 cylinders which meet DOT requirements (i.e., conforming cylinders) for shipment from the three sites to a conversion or storage facility
- Preparation of depleted UF_6 cylinders which do not meet DOT requirements (i.e., nonconforming cylinders) for shipment from the three sites to a conversion or storage facility
- Treatment of emptied cylinders
- Loading, shipping, and unloading of depleted UF_6, emptied cylinders, U_3O_8, UO_2, uranium metal, uranium metal shields, and oxide (DUCRETE™) shields

Cost for shipping other materials such as input reagents for chemical conversion processes (e.g., ammonia, sodium hydroxide, hydrochloric acid) and output by-products (e.g., AHF) are included in the cost of purchasing the reagents or in the revenues generated from selling the by-products.

4.1.1 Preparation for Shipment

Preparation for shipment includes the cost of preparing conforming cylinders plus the cost of preparing nonconforming cylinders. The preparation cost for the latter is the cost of placing nonconforming cylinders in cylinder overcontainers <u>or</u> the cost of transferring depleted UF_6 from cylinders that no longer meet DOT requirements to new or conforming cylinders.

The number of cylinders that will not meet transportation requirements over the shipping time frame is not precisely known. The costs for preparing the cylinders for shipment are based upon the reference case of approximately 29,000 nonconforming cylinders and 17,000 conforming cylinders. Other cases are presented in Section 6.2.1.

The cost of preparing conforming cylinders for shipment is presented in Table 4.1. Tables 4.2 and 4.3 present the costs of the two options for preparing nonconforming cylinders for shipment, the cylinder overcontainer option and the transfer facility option. The overcontainer option has a much lower estimated cost because process facilities are not necessary and the operations and maintenance activities are simpler and therefore less costly. However, if development and fielding of an overcontainer (which currently does not exist) is adversely impacted by changes in transportation regulations or other factors, the transfer facility provides another option for preparing nonconforming cylinders for shipment.

Three facilities would be required for the transfer option—one at Paducah for transferring 19,200 cylinders, one at Portsmouth for transferring 5,200 cylinders, and one at K-25 for transferring 4,683 cylinders. Table 4.3 shows the combined cost for the three transfer facilities. The costs for the transfer facility option were evaluated by combining the costs of engineering development, process equipment, process facilities, balance of plant, regulatory compliance, operations and maintenance, and decontamination and decommissioning.[2] Process facilities for the transfer facility include the engineering and construction of a two-story reinforced concrete process building to house autoclaves and other process equipment. Most of the transfer facility process building is special construction with area perimeter walls and ceilings assumed to be 1-ft thick concrete, interior walls assumed to be 8-in. thick concrete, and base mat assumed to be 2-ft thick concrete.

4.1.2 Treatment of Emptied Cylinders

Most of the management strategy alternatives involve removing the depleted UF_6 from the cylinders and converting it to another form, which would generate 46,422 emptied cylinders for disposition. Transfer of the depleted UF_6 into new or conforming cylinders for future storage is another option requiring treatment of emptied cylinders. A preconceptual design for a stand-alone facility for removal of the depleted UF_6 heel from the emptied cylinders is included in the *Engineering Analysis Report*. After the heel is washed from the cylinders, the wash solution is neutralized for disposal and the cylinders are crushed for shipment to DOE scrap metal facilities.

The qualitative and quantitative impacts of collocating the treatment facility with either a metal or oxide conversion facility were analyzed. The collocation would lead to a significant reduction in the required infrastructure, including labor, storage yards for temporary storage of incoming/outgoing emptied cylinders, support buildings, roadwork, grounds, and piping. In addition, the cylinder treatment function would become a processing module within the conversion facility. Table 4.4 presents the incremental costs for integrating the cylinder treatment function into a conversion facility. The estimates for a treatment facility collocated with an oxide conversion facility are about one-quarter the stand-alone costs, while the estimate for a treatment facility collocated with a metal conversion facility are about one-third the stand-alone costs. The cost of a collocated treatment facility is the basis for emptied cylinder disposition costs for the management strategy alternatives.

4.1.3 Loading, Shipping, and Unloading

Loading, shipping, and unloading full depleted UF_6 cylinders, emptied depleted UF_6 cylinders, drums of U_3O_8, drums of UO_2, boxes of uranium metal, uranium metal shields, and oxide (DUCRETE™) shields are included in this cost element. Table 4.5 and Figure 4.1 compare the shipping costs, including loading and unloading, by truck and rail for all the management strategies. Other than shipments originating from the current storage sites, origins and destinations are unknown at this time. For the reference case, a distance of 1000 km was assumed for all shipments. Other cases are considered in Section 6.1.2.

Estimated costs per kilometer traveled and for loading and unloading are lower for truck than for rail ($1.79/km, $100/load, and $100/unload per truckload versus $1.86/km, $1000/load, and $1000/unload per railcar). However, at the assumed distance of 1000 km, the total cost of transport is lower by rail. In general, more material can be placed on a railcar than a truck (approximately a factor of 3 by weight), resulting in a lower cost per kilometer per kilogram of material moved. For distances greater than around 500 km, this outweighs the higher loading/unloading costs and rail is less expensive, but for shorter

[2] Due to the discount effect, costs occurring late in the campaign, such as decontamination and decommissioning, appear to be quite small compared with those such as technology development, which occur early in the campaign.

distances, truck transport would have the lower costs. It is noted that rail costs are influenced by location more than trip distance and therefore have a much higher associated uncertainty than truck transportation costs since locations have not been determined.

4.1.4 Total Transportation Costs

The total transportation costs are presented in Tables 4.6 and 4.7 and are computed as the sum of the costs described in Sections 4.1.1 through 4.1.3. Table 4.6 and Figure 4.2 present the estimate for the low-cost transportation options (i.e., overcontainers for nonconforming cylinders and rail for transport mode). Table 4.7 and Figure 4.3 present the estimate for the high-cost transportation options (i.e., a transfer facility for nonconforming cylinders and truck for transport mode).

Table 4.1 Cost Breakdown (in Millions of Dollars) for Preparation of (17,339) Conforming Cylinders for Shipment

Inspection and retrieval equipment	
Engineering	0.17
Fabrication	1.39
Certification	0.07
Subtotal	1.63
Handling fixtures	
Engineering	0.06
Fabrication	0.47
Certification	0.02
Subtotal	0.55
Shipping fixtures	
Engineering	0.02
Fabrication	0.16
Certification	0.01
Subtotal	0.19
Facilities	
Engineering	0.00
Construction	0.00
Project management	0.00
Subtotal	0.00
Regulatory compliance	1.13
Operations and maintenance	
Materials	1.64
Utilities	0.01
Labor	44.27
Waste Management & Disposal	0.19
Subtotal	46.11
Decontamination & decommissioning	0.00
TOTAL	49.61

Table 4.2 Cost Breakdown (in Millions of Dollars) for Preparation of (29,083) Nonconforming Cylinders for Shipment - Overcontainer Option

Engineering Technology	0.82
Inspection and retrieval equipment	
Engineering	0.23
Fabrication	1.93
Certification	0.09
Subtotal	2.25
Overcontainers	
Engineering	0.54
Fabrication	2.39
Certification	0.15
Subtotal	3.08
Handling fixtures	
Engineering	0.06
Fabrication	0.47
Certification	0.02
Subtotal	0.55
Shipping fixtures	
Engineering	0.03
Fabrication	0.24
Certification	0.01
Subtotal	0.28
Facilities	
Engineering	0.00
Construction	0.00
Project management	0.00
Subtotal	0.00
Regulatory compliance	1.13
Operations and maintenance	
Materials	6.60
Utilities	0.03
Labor	96.03
Waste Management & Disposal	0.33
Subtotal	102.99
Decontamination & decommissioning	0.00
TOTAL	111.10

Table 4.3 Cost Breakdown (in Millions of Dollars) for Preparation of (29,083) Nonconforming Cylinders for Shipment - Transfer Facility Option

Engineering Development	2.46
Process Equipment	
Engineering	3.70
Fabrications	8.01
Installation	5.24
Certification & Test	0.35
Subtotal	17.30
Process Facilities	
Engineering	16.86
Construction	49.04
Proj. Management	10.97
Subtotal	76.87
Balance of Plant	
Engineering	12.46
Construction	36.26
Proj. Management	8.11
Subtotal	56.83
Regulatory Compliance	56.20
Operations and Maintenance	
Material	82.78
Utilities	28.17
Labor	278.51
Waste Management & Disposal	4.70
Subtotal	394.16
Decont. & Decom.	2.71
TOTAL	604.07

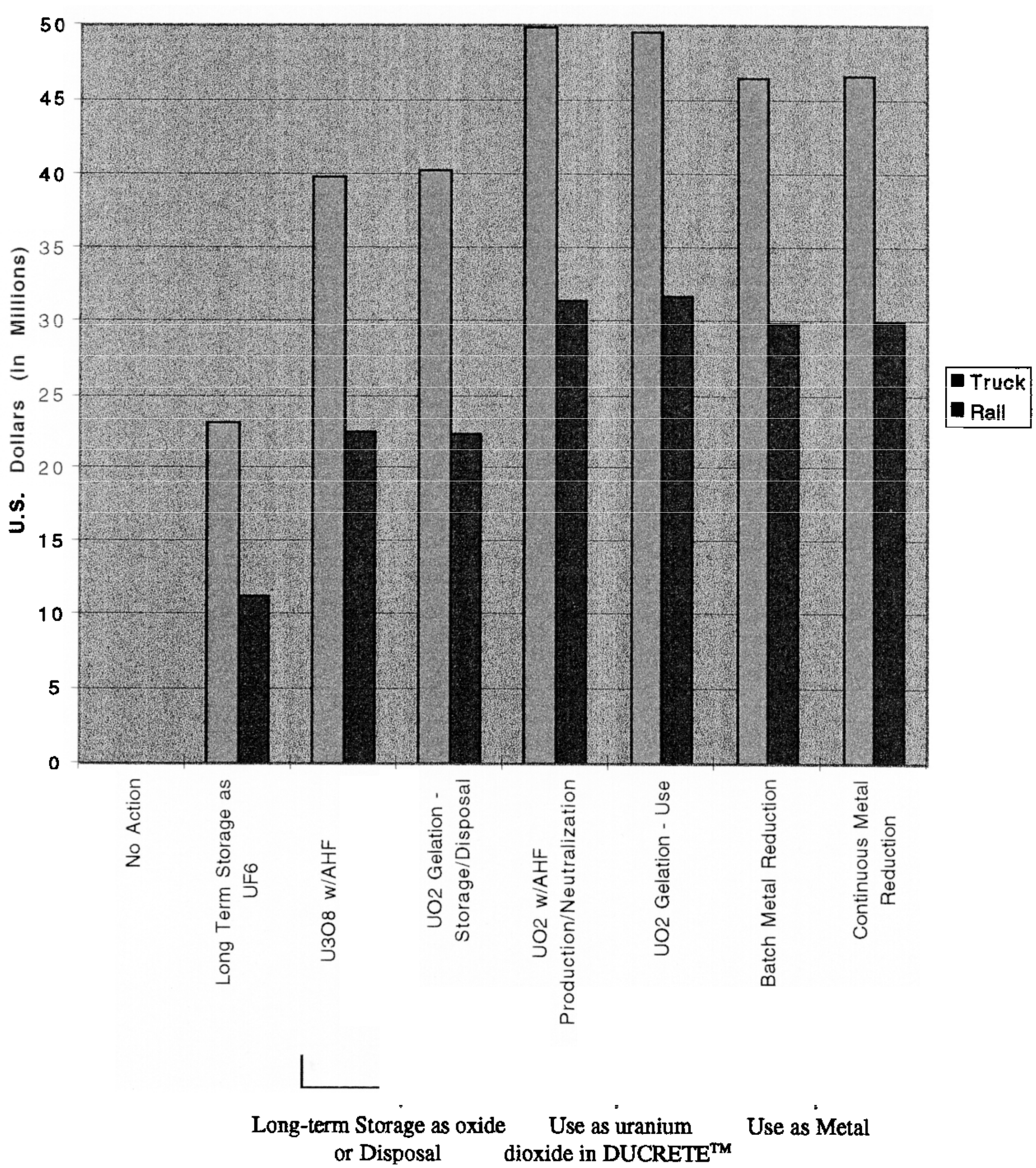
Table 4.4 Cost Breakdown (in Millions of Dollars) for Emptied Cylinder Disposition

	Integration into Oxide Conversion Facility	Integration into Metal Conversion Facility
Technology Development	1.64	1.64
Facility Capital Cost		
Engineering	0.94	1.52
Construction	3.43	5.54
Project management	0.63	1.01
Subtotal	5.00	8.07
O & M		
Labor	0.89	1.24
Utilities	0.09	0.12
Materials	0.04	0.04
Waste Management & Disposal	0.49	0.49
Subtotal	1.51	1.89
D & D	0.11	0.11
TOTAL	8.26	11.71

Table 4.5 Loading, Shipping, and Unloading Cost Breakdown (in Millions of Dollars) by Truck and Rail

	No Action		DUF_6 Long Term Storage		U_3O_8 w/AHF Production/Neutralization *Storage/Disposal*		UO_2 Gelation *Storage/Disposal*		UO_2 w/AHF Production/Neutralization *Storage/Disposal*		UO_2 Gelation *Use*		Batch Metal Reduction *Use*		Continuous Metal Reduction *Use*	
	truck	rail	truck	rail	truck	rail	truck	rail	truck	rail	truck	rail	truck	rail	truck	rail
From Current Site to Conversion Facility	0.00	0.00	-	-	23.25	11.28	23.25	11.28	23.25	11.28	23.25	11.28	23.25	11.28	23.25	11.28
From Conversion Site to Storage/Disposal Site	0.00	0.00	-	-	12.76	8.70	13.14	8.55	-	-	-	-	-	-	-	-
From Conversion Site to DUCRETE™ Container Manufacturer	-	-	-	-	-	-	-	-	13.41	8.24	13.14	8.55	-	-	-	-
From DUCRETE™ Container Manufacturer to SNF Container User	-	-	-	-	-	-	-	-	rail 9.33	9.33	rail 9.33	9.33	-	-	-	-
From Conversion Site to Metal Annulus Manufacturer	-	-	-	-	-	-	-	-	-		-	-	10.43	7.15	10.76	7.30
From Metal Annulus Manufacturer to SNF Container User	-	-	-	-	-	-	-	-	-	-	-	-	rail 8.86	8.86	rail 8.86	8.86
From Conversion Facility to Cylinder Treatment Facility	0.00	0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00
From Cylinder Treatment Facility to DOE Yards (crushed cylinders)	0.00	0.00	-	-	3.87	2.51	3.87	2.51	3.87	2.51	3.87	2.51	3.87	2.51	3.87	2.51
From Current Site to Storage	-	-	23.25	11.28	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	0.00	0.00	23.25	11.28	39.88	22.49	40.26	22.34	49.86	31.36	49.59	31.67	46.41	29.80	46.74	29.95

Figure 4.1 Total Cost by Truck and Rail for the Various Management Strategies



		M	w/AHF Produ			AHF	M		Redu		AHF		
Preparation of Nonconforming Cylinders for Shipment	0.00	111.10	111.10	111.10	111.10	111.10	111.10	111.10	111.10	111.10	111.10	111.10	111.10
Emptied Cylinder Disposition	0.00	0.00	8.26	8.26	8.26	8.26	8.26	8.26	11.72	11.72	8.26	8.26	8.26
Total Loading, Shipping, Unloading for rail	0.00	11.28	22.49	22.49	22.34	31.36	31.36	31.67	29.80	29.95	22.49	22.49	22.34
TOTAL	0.00	171.99	191.46	191.46	191.31	200.33	200.33	200.64	202.23	202.38	191.46	191.46	191.31

Figure 4.2 Total Costs for Transportation Using Overcontainer and Rail

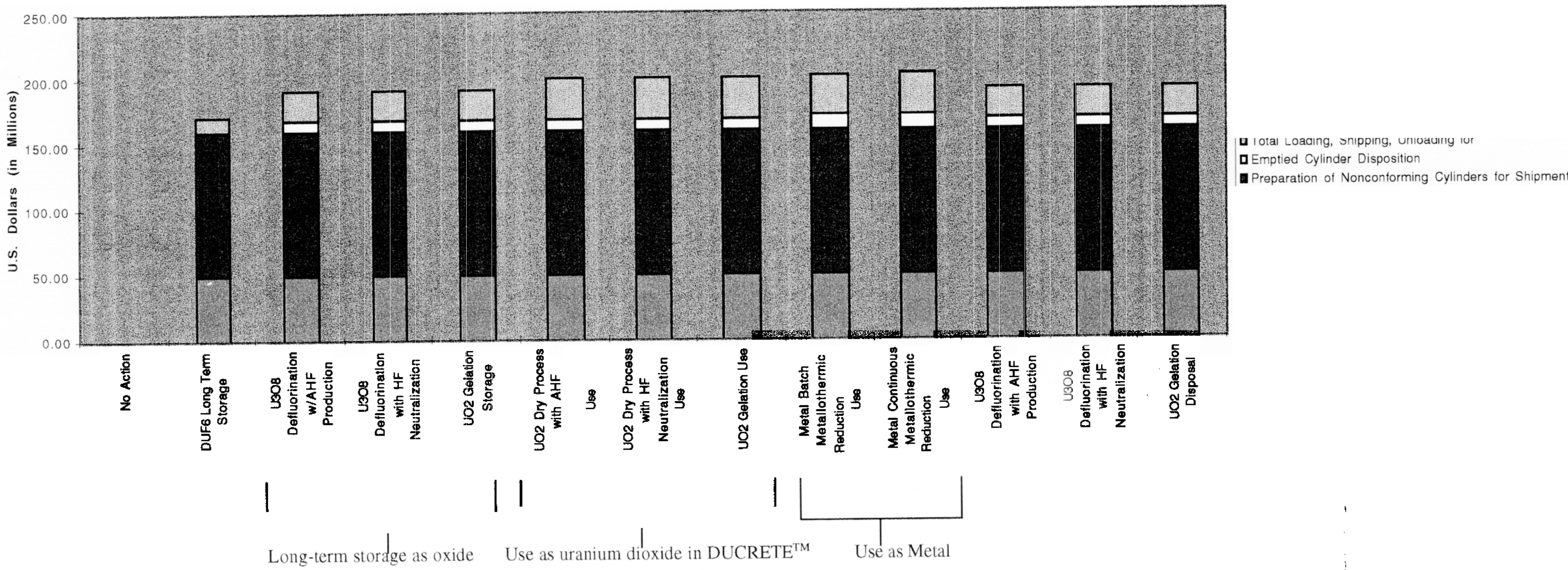
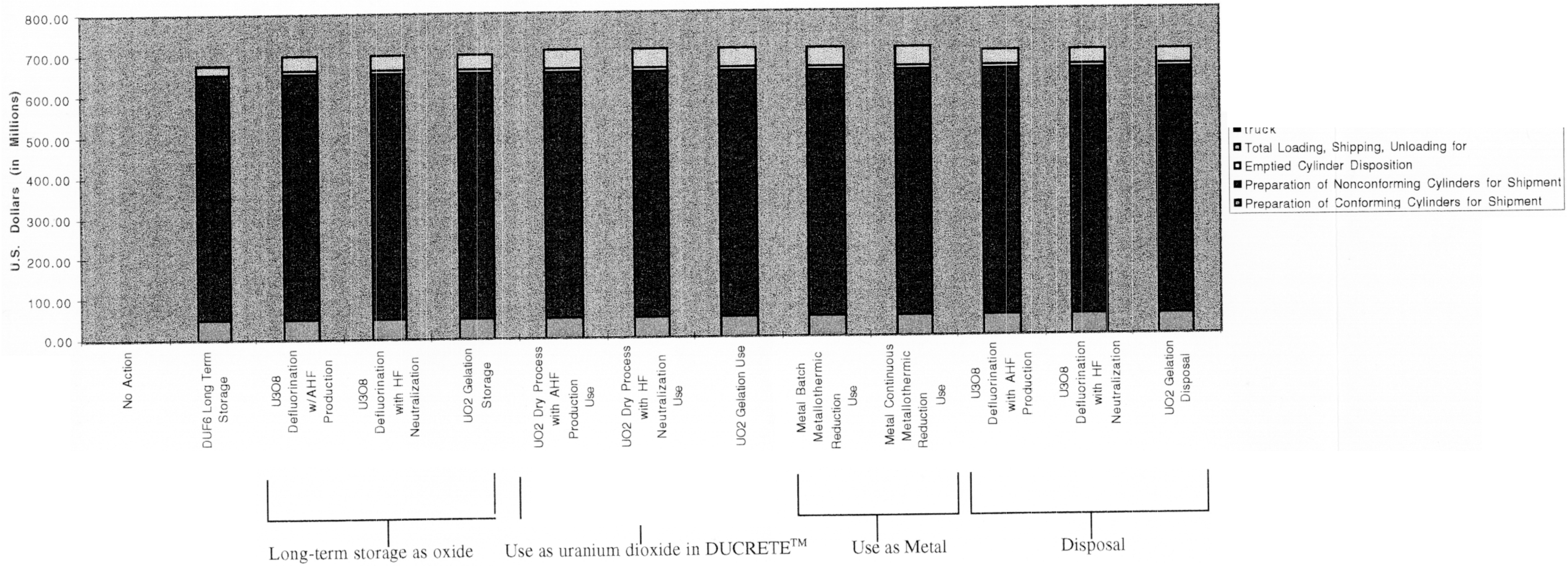


Table 4.7 Cost Breakdown (in Millions of Dollars) for Transportation Using the Transfer Facility Option for the Preparation of (29,083) Nonconforming Cylinders and the Truck Option for the Mode of Transportation

	No Action	DUF_6 Long Term Storage	U_3O_8 Defluorination w/AHF Production *Storage*	U_3O_8 Defluorination with HF Neutralization *Storage*	UO_2 Gelation *Storage*	UO_2 Dry Process with AHF Production *Use*	UO_2 Dry Process with HF Neutralization *Use*	UO_2 Gelation *Use*	Metal Batch Metallothermic Reduction *Use*	Metal Continuous Metallothermic Reduction *Use*	U_3O_8 Defluorination with AHF Production *Disposal*	U_3O_8 Defluorination with HF Neutralization *Disposal*	UO_2 Gelation *Disposal*
Preparation of Conforming Cylinders for Shipment	0.00	49.61	49.61	49.61	49.61	49.61	49.61	49.61	49.61	49.61	49.61	49.61	49.61
Preparation of Nonconforming Cylinders for Shipment	0.00	604.07	604.07	604.07	604.07	604.07	604.07	604.07	604.07	604.07	604.07	604.07	604.07
Emptied Cylinder Disposition	0.00	0.00	8.26	8.26	8.26	8.26	8.26	8.26	11.72	11.72	8.26	8.26	8.26
Total Loading, Shipping, Unloading for truck	0.00	23.25	39.88	39.88	40.26	49.86	49.86	49.59	46.41	46.74	39.88	39.88	40.26
TOTAL	0.00	676.90	701.79	701.79	702.17	711.77	711.77	711.50	711.78	712.11	701.79	701.79	702.17

Figure 4.3 Total Costs for Transportation Using Transfer Facility and Truck



4.2 Conversion

Conversion of the depleted UF_6 to another chemical form is required for most management strategy alternatives. The following conversion options are considered:

- Conversion to triuranium octaoxide (U_3O_8)
- Conversion to uranium dioxide (UO_2)
- Conversion to metallic uranium

Two different processes for the conversion to U_3O_8, three different processes for the conversion to UO_2, and two different processes for the conversion to metal were analyzed.

4.2.1 Conversion Costs

The costs of the conversion options are summarized in Table 4.8, which reflects costs at CBS Level 6. These costs were evaluated by combining the costs for technology development, process equipment, process facilities, balance of plant, regulatory compliance, operation and maintenance, and decontamination and decommissioning. The process equipment estimate provides costs for the major process equipment, as well as costs for process piping and instrumentation. Costs are based on vendor quotes (where available), historical costs of similar equipment in similar service, current estimating/pricing manuals, or estimated costs of equipment of the same complexity and materials of construction.

Process facilities include costs for buildings and supporting equipment. All major buildings are structural steel frame of standard construction, with the following exceptions:

- The process building is a two-story reinforced concrete structure. Most of this building is "special construction," with "standard construction" support areas, as shown on the layout figures in the *Engineering Analysis Report*. The "special construction" area perimeter walls and ceilings are assumed to be 1-ft thick concrete; interior walls are assumed to be 8-in. thick concrete; and the base mat is assumed to be 2-ft thick concrete. The "standard construction" area walls are assumed to be 8-in. thick concrete; ceilings and elevated floor areas are assumed to be 6-in. thick concrete on metal deck; and the floor slab on grade is assumed to be 8-in. thick concrete.

- The AHF storage building for options producing AHF by-product is a reinforced concrete structure, designed and constructed as "special construction." The walls are assumed to be 8-in. thick concrete; ceilings are assumed to be 6 inches of concrete on metal deck; and the floor slab is assumed to be 2-ft thick concrete.

The operation and maintenance costs include labor, materials, utilities, and waste management and disposal costs necessary to operate the facility at design capacity for 20 years. Conversion to metal produces the salable by-product AHF and waste MgF_2, which is assumed to be disposed as sanitary waste at a cost of $2/cubic foot. Section 6.3.2 discusses the cost impacts if disposal as LLW were required. Conversion to oxide produces either AHF or, when the HF is neutralized, CaF_2. It is noted that neutralization of the HF produced by conversion processes results in higher estimated costs than production and sale of AHF. Section 4.2.2 describes the assumptions regarding the sale of AHF and CaF_2 by-products. Section 6.3.1 describes vulnerabilities associated with sale of these by-products and estimates the cost impacts if disposal were necessary.

Figure 4.4 compares the costs of the various conversion options. With the exception of the gelation process for producing UO_2, conversion costs are lowest for conversion to U_3O_8 and highest for conversion to uranium metal. Conversion to UO_2 using the dry process is higher than conversion to U_3O_8, while gelation process costs are slightly more than double the dry process costs for conversion to UO_2. Costs for all conversion options are dominated by the operations and maintenance costs. Operations and maintenance costs for the gelation process, particularly materials (which is a factor of almost 4 higher), are more than double the operations and maintenance costs for other options for the conversion to UO_2.

The gelation process produces UO_2 microspheres with a bulk density about 50% higher than the dry conversion processes, which produce pellets. This leads to a reduction in storage and disposal volumetric requirements, and therefore the gelation process minimizes costs for the storage and disposal options involving the oxide. These considerations are further discussed in Section 6.1.4. There are also a number of technical uncertainties with respect to the gelation process, including a practical recovery and recycle process for major process reagents. In the absence of such a process, the effluent stream containing these reagents was assumed to be discarded as a sanitary waste. Recycling these reagents would significantly improve the economics and viability of the gelation process.

The batch metallothermic reduction option for producing metal is estimated to cost significantly more than the continuous metallothermic reduction option. Batch reduction is a mature process with decades of industrial use. The continuous reduction process is still in development. These differences are further discussed in the *Engineering Analysis Report*, Section 3.2.3.

4.2.2 Revenue from Sale of By-product AHF and CaF_2

All of the conversion options produce potentially salable by-products—either AHF or CaF_2. Three of the oxide conversion options and both of the metal conversions options produce AHF. Defluorination with AHF production is superior to defluorination with HF neutralization in terms of by-product value and waste avoidance. In the unlikely event that the recovered AHF (because of the small [< 1 ppm] uranium concentration) could not be sold for unrestricted use or the even more unlikely event that it could not be recycled in the nuclear fuel industry, the concentrated HF would be neutralized with lime (CaO) to form CaF_2. Neutralization of HF may also be undertaken to avoid storage and transportation of large quantities of hazardous AHF. Neutralization would further reduce the already small concentration of uranium in the by-product. In the absence of regulatory constraints regarding the uranium content, the CaF_2 could be sold as a feedstock (i.e., a high-quality fluorspar substitute) for the commercial production of AHF. The by-product value of CaF_2 is significantly less than AHF and major quantities of lime would be required for neutralization, adding to the cost of input reagents.

The largest use of AHF is in the manufacture of fluorocarbons. The fluorocarbon market accounts for about 65-70% of AHF demand and is thus the primary driving force in hydrogen fluoride demand. Forecasting fluorocarbon demand is still a very uncertain exercise. Although the replacement fluorocarbons use more hydrogen fluoride per unit than the chlorinated fluorocarbons, representatives of the major North American fluorocarbon producers are divided in forecasting demand. It should be noted that the annual production of by-product AHF from an oxide conversion facility (28,000 MT/yr. UF_6) is about 9,200 MT. This is approximately 5% or less of the estimated U.S. annual capacity for HF production.

In addition to the uncertain market, there is concern about possible public reaction to uranium contaminants. If the fluorine chemical is to be sold in North America, it may be subjected to higher purity standards due to the source material. Allied Signal has proposed to overcome this potential problem by using the AHF in nuclear reactor fuel production. The aqueous HF produced by Cogema in France as part of their defluorination process is viewed by potential European purchasers outside the nuclear fuel cycle as very pure and highly desirable. It is marketed to outside buyers in the glass and steel industries. The uranium content of this high purity HF is below the 0.1 ppm uranium instrument detection levels, well within the 5 ppm specification for aqueous HF sales in Europe.

The major potential buyers for AHF negotiate prices. The price published in the *Chemical Market Reporter* (formerly *Chemical Marketing Reporter*) (CMR) of $1.5125/kg was used in this analysis, although the actual price would be negotiated at the time of sale. Prices in the CMR were checked between June 30, 1995, and March 29, 1996, and there was no change. It should be noted that chemical prices quoted in the CMR come with a disclaimer to the effect that they are based on price information obtained from suppliers and do not necessarily represent levels at which transactions actually may have occurred.

Calcium fluoride is a potential major feed stock for HF production as a substitute for mined fluorspar. If a market could be found, possible fluorspar prices are $97.66/ton ($.10736/kg) (U.S. Department of Interior). In the previous three years, fluorspar prices had declined slightly and steadily to the current level. This is partly due to an increase in Chinese fluorspar and increased U.S. government licensing for fluorspar mining.

Table 4.9 shows the annual revenue from sale of AHF and CaF_2 by-products produced from conversion of depleted UF_6 to other uranium forms. The prices quoted above were used to calculate these revenues. The discounted values (7% p.a.) of the revenue stream over the 20-year conversion campaign are shown in Table 4.8.

Table 4.8 Cost Breakdown (in Millions of Dollars) for Conversion Options

	U_3O_8		UO_2			Metal	
	With AHF Production	With HF Neutralization	With AHF Production	With HF Neutralization	Gelation	Batch Metallothermic Reduction	Continuous Metallothermic Reduction
Tech. Development	9.84	5.74	13.94	9.84	24.60	4.92	20.50
Process Equipment							
Engineering	4.74	4.43	7.74	7.13	21.98	7.80	6.52
Fabrication	11.91	10.93	18.96	17.41	51.81	17.98	15.22
Installation	5.19	5.04	8.91	8.27	27.18	10.03	8.20
Certification & Test	0.52	0.48	0.83	0.76	2.26	0.79	0.66
Subtotal	22.36	20.88	36.44	33.57	103.23	36.60	30.60
Process Facilities							
Engineering	10.16	9.98	14.91	13.58	23.89	18.27	16.09
Construction	29.56	29.05	43.39	39.50	69.51	53.14	46.82
Proj. Management	6.61	6.50	9.71	8.84	15.55	11.89	10.47
Subtotal	46.33	45.53	68.01	61.92	108.95	83.30	73.38
Balance of Plant							
Engineering	6.40	6.63	7.76	7.66	13.08	8.33	8.22
Construction	18.63	19.30	22.57	22.29	38.04	24.22	23.91
Proj. Management	4.17	4.32	4.12	4.99	8.51	5.42	5.35
Subtotal	29.20	30.25	34.45	34.94	59.63	37.97	37.48
Regulatory Compliance	22.70	22.70	22.70	22.70	22.70	22.70	22.70
Operations and Maintenance							
Material	52.71	55.96	66.12	66.45	261.94	189.74	171.76
Utilities	12.83	13.10	14.55	14.82	46.05	23.84	13.30
Labor	134.68	137.44	152.72	155.48	242.11	250.19	139.57
Waste Management & Disposal	11.86	2.92	12.47	3.47	24.45	39.14	6.14
By-product Revenue	-77.32	-11.02	-77.31	-11.02	-77.32	-26.11	-26.11
Subtotal	134.76	198.40	168.55	229.20	497.23	476.80	304.66
Decont. & Decom.	1.76	1.73	2.51	2.34	4.87	2.83	2.54
TOTAL	266.95	325.23	346.60	394.51	821.21	665.12	491.86

Figure 4.4 Total Costs for Different Conversion Options

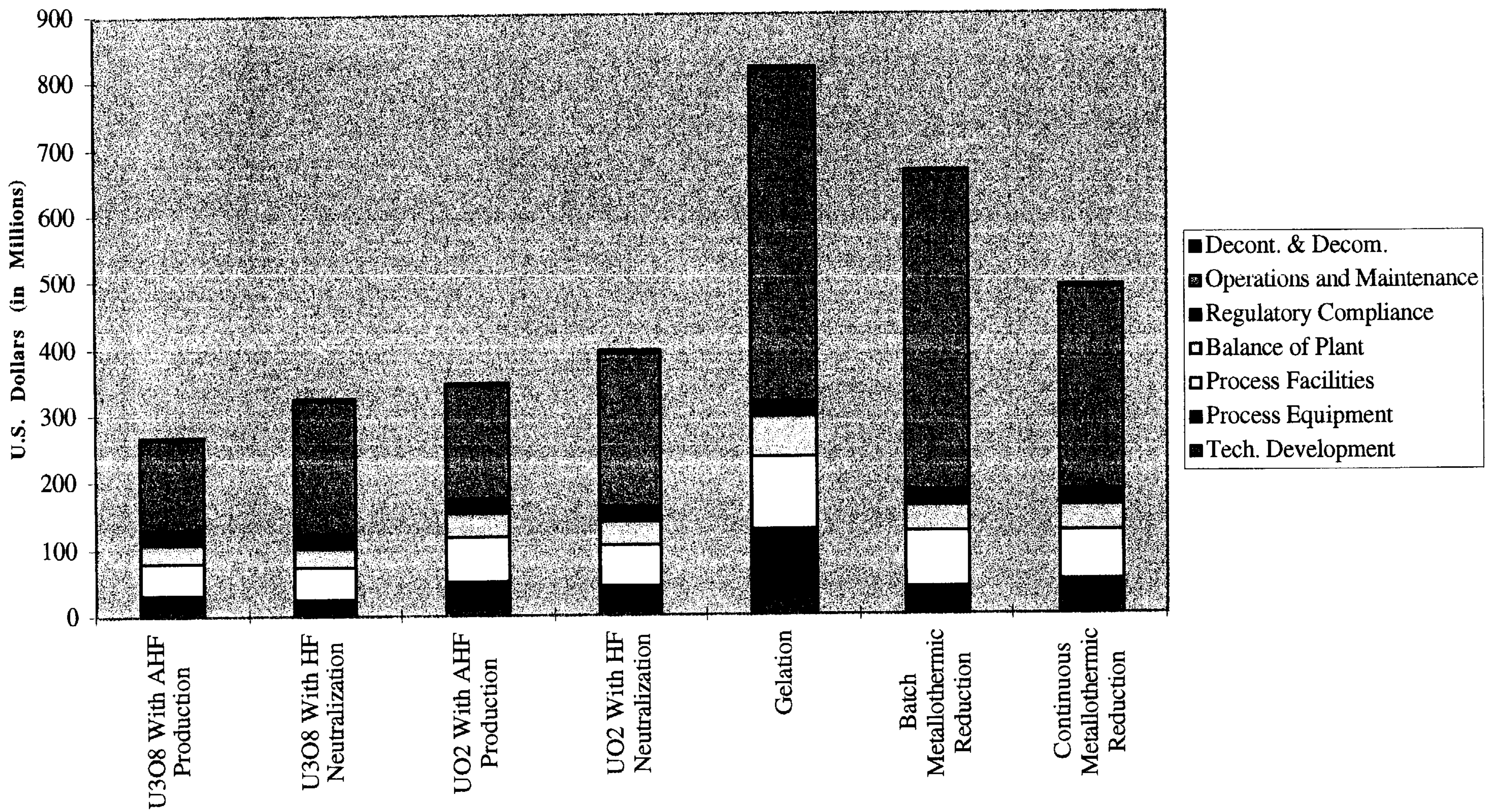


Table 4.9 Annual Revenue from Sale of AHF and CaF_2 By-products from Conversion Options in Millions of Dollars

Option	Quantity (MT)	Reference Case
U_3O_8 w/AHF Production	9,237 AHF 419 CaF_2	Revenue from AHF: 13.97 Revenue from CaF_2: 0.045
U_3O_8 w/HF Neutralization	CaF_2 18,600	Revenue from CaF_2: 1.99
UO_2 w/AHF	9,237 AHF 421 CaF_2	Revenue from AHF: 13.97 Revenue from CaF_2: 0.045
UO_2 w/HF Neutralization	CaF_2 18,600	Revenue from CaF_2: 1.99
UO_2 Gelation	9,237 AHF 421 CaF_2	Revenue from AHF: 13.97 Revenue from CaF_2: 0.045
Batch metallothermic reduction to uranium metal	3,121 AHF 118 CaF_2	Revenue from AHF: 4.72 Revenue from CaF_2: 0.013
Continuous metallothermic reduction to uranium metal	3,121 AHF 118 CaF_2	Revenue from AHF: 4.72 Revenue from CaF_2: 0.013

4.3 Manufacture and Use

There is a potential use for depleted uranium in radiation shielding applications, specifically for storage, transportation, or disposal containers for spent nuclear fuel (SNF). Two manufacturing options were considered: oxide shielding (DUCRETE™) and uranium metal shielding. In the oxide shielding application, dense UO_2 would be substituted as the aggregate in standard concrete for the construction of containers for the dry storage of SNF. In the metal shielding application, molten depleted uranium metal would be cast into a component of a multipurpose unit suitable for the storage, transportation, and disposal of SNF.

The total shielding cost was evaluated by combining the costs of engineering development, manufacturing equipment, manufacturing facilities, balance of plant, regulatory compliance, operations and maintenance, and decontamination and decommissioning. The cost of the depleted uranium is excluded from this estimate because the cost of converting depleted UF_6 to depleted uranium metal or dense UO_2 is captured in the conversion options and is part of any use alternative. The operations and maintenance costs include the labor, materials, utilities, and waste management and disposal costs necessary to operate the facility at design capacity for 20 years.

No credit has been taken in the reference case for either the metal or the DUCRETE™ casks. Use of the DUCRETE™ casks for dry storage of spent nuclear fuel would avoid the cost of the standard vertical concrete containers currently available. Similarly, use of metal casks would avoid the cost of other options. In addition, these applications could delay costs associated with disposal of depleted uranium. If the depleted uranium casks are also used for the disposal of the spent nuclear fuel, future depleted uranium disposal costs could be avoided altogether. Cases which consider a cask credit are found in Section 6.1.3.

The manufacturing equipment estimate provides costs for the major process equipment, including process piping and instrumentation. Costs are based on vendor quotes (where available), historical costs of similar equipment in similar service, current estimating/pricing manuals, or estimated costs of equipment of the same complexity and materials of construction.

Manufacturing facilities include costs for buildings and supporting equipment. The main processing buildings for the two applications differ due to the types of shielding materials produced and the forming operations required. The main processing building for the metal shielding application is a reinforced concrete, high-bay structure, while the main processing building for the oxide shielding application is based upon standard construction concrete block and spread footers.

The costs for oxide and metal shielding are summarized in Table 4.10 and compared in Figure 4.5. The estimated costs for the metal and oxide shielding applications are similar. The majority of the costs for both options are operations and maintenance costs. For metal shielding, operations and maintenance costs account for 87% of total shielding cost. For oxide shielding, they account for 89% of total shielding cost.

Table 4.10 Cost Breakdown (in Millions of Dollars) for Manufacture of Metal and Oxide Shielding Options

	Metal Shielding	Oxide Shielding
Engineering Development	16.40	6.56
Manufacturing Equipment		
Engineering	4.11	3.94
Fabrication	11.55	11.06
Installation	3.19	3.06
Certification and Test	0.51	0.49
Subtotal	19.36	18.55
Manufacturing Facilities		
Engineering	7.64	6.87
Construction	22.26	20.02
Project Management	4.99	4.49
Subtotal	34.89	31.38
Balance of Plant		
Engineering	5.95	4.94
Construction	17.31	14.36
Project Management	3.88	3.22
Subtotal	27.14	22.52
Regulatory Compliance	17.43	17.43
Operations & Maintenance		
Materials	311.49	296.05
Utilities	42.30	42.41
Labor	415.13	416.18
Waste Management	3.70	3.92
Cask Credit	0.00	0.00
Subtotal	772.62	758.56
Decontamination & Decommissioning	1.46	1.30
TOTAL	889.30	856.30