LOUISIANA ENERGY

Post Office Box 1004
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October 1, 1991

Charles J. Haughney, Chief
Fuel Cycle Safety Branch
Division of Industrial and
Medical Nuclear Safety
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Re: Docket No.: 70-3070
Louisiana Energy Services
Claiborne Enrichment Center
Request for Additional Information
Disposition of Depleted Uranium Hexafluoride
File: MTS-6046-00-2001.01

Dear Mr. Haughney:

Enclosed are four copies of Louisiana Energy Services' Depleted Uranium Hexafluoride Management Study as requested by item ER-7 of your letter dated March 21, 1991. Appendix B of this report describes the requirements for the depleted uranium hexafluoride cylinder surveillance and maintenance program as requested by item SAR-4 of your letter dated March 21, 1991.

If there are any questions concerning this, please do not hesitate to call me at (704) 373-8466.

Very truly yours,

Peter G. LeRoy

Peter G. LeRoy
Licensing Manager

PGL/N15.991

cc: Diane Curran, Esquire
Harmon, Curran & Tousley
2001 S Street, NW, Suite 430
Washington, DC 20009

EX# 6

LOUISIANA ENERGY SERVICES
CLAIBORNE ENRICHMENT CENTER

DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT STUDY

OCTOBER 1, 1991

DUKE ENGINEERING
& SERVICES, INC.

LOUISIANA ENERGY SERVICES
CLAIBORNE ENRICHMENT CENTER

DEPLETED URANIUM HEXAFLUORIDE MANAGEMENT STUDY

BY
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JN UNDERWOOD
ENGINEERING MANAGER

OCTOBER 1, 1991

DUKE ENGINEERING
& SERVICES, INC.

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EXECUTIVE SUMMARY

This report evaluates options and recommends actions to ensure that the depleted uranium hexafluoride (UF_6) produced at the Claiborne Enrichment Center (CEC) is handled in a safe and cost-effective manner in accordance with all applicable regulations to protect the environment, as summarized in Section 2.0 of the CEC Safety Analysis Report (SAR).

A primary guiding principle is to maximize the potential for utilization of the depleted uranium to reduce disposal requirements. This involves storage of the depleted UF_6 onsite while pursuing opportunities to employ this material as a resource. As discussed in Section 5.0, this storage will be at the CEC in the form of UF_6, in cylinders that have been designed, tested, and inspected in accordance with American National Standard ANSI N14.1, and NRC regulation 10 CFR 50 Appendix B.

All depleted UF_6 which has not been utilized by the end of the operation of the CEC will be removed from the site. If it can not be used elsewhere, it will be converted to a form suitable for disposal and disposed of in a licensed repository. A method currently available is to convert the depleted UF_6 to uranium tetrafluoride (UF_4), and dispose of it in a low-level radioactive waste facility. While other options may prove more practical in the future (i.e., conversion to U_3O_8 which is the preferred form for long-term storage and disposal), this method can be implemented in the United States at the present, and thus is used for the decommissioning cost basis. The UF_4 is a suitably stable material for packaged disposal, and the conversion process exists on a commercial scale.

Section 11.8 of the CEC SAR contains the Louisiana Energy Services (LES) estimate that the conversion of UF_6 to UF_4 and disposal will cost $9.5 million at decommissioning per year of CEC operation (based on 300 cylinders of depleted UF_6 per year) in 1990 dollars, assuming the worst case of no utilization. This amount will accumulate as the plant operates, and will be reviewed and updated periodically along with other plant decommissioning costs, with adjustments made as needed.

1.0 INTRODUCTION

1.1 PURPOSE

Operation of the Louisiana Energy Services (LES) Claiborne Enrichment Center (CEC) will produce depleted uranium hexafluoride (DUF_6). This report describes the options for management of DUF_6 during the operational life of the plant and during decommissioning of the plant as part of the CEC licensing requirements.

1.2 SCOPE

This report covers two distinct aspects of DUF_6 management at the CEC. The first aspect is management of DUF_6 during CEC operation. This time period is from the expected receipt of UF_6 on the CEC site in 1995 until the expiration in 2023 of the operating license. The second aspect is the removal of DUF_6 from the site during the decommissioning period from 2023 until 2028.

Each time period described above was analyzed independently and a list of options for each period was developed. These options were analyzed in accordance with the criteria described in Section 2.0 to determine the course of action to be taken by LES that is the most environmentally suitable, safe, and cost-effective. The conclusions from this report are described in Section 4.0 and a list of recommendations for LES to pursue are contained in Section 5.0.

1.3 BACKGROUND

This section provides background information on uranium enrichment, uranium hexafluoride (UF_6), and current and future trends for use of DUF_6 in the industry. This information is important for the evaluation of the viability of future options.

1.3.1 Enrichment Processes

Uranium exists naturally as a combination of isotopes, primarily consisting of the stable isotope U238. Approximately 0.71 percent of naturally occurring uranium exists as the fissile isotope U235. U235 is the only naturally occurring fissile isotope of uranium. For commercial purposes, the concentration of the U235 isotope must be increased to as much as 5 percent. The process of increasing the U235 concentration is "enrichment." This process can be performed in several different ways, as described in the following sections.

1.3.1.1 Gaseous Diffusion

The original uranium enrichment method used on a large scale in the U.S. was gaseous diffusion. In this method, UF_6 in gaseous form is passed through a specially constructed porous membrane. UF_6 incorporating U235 flows through the membrane at a slightly faster rate than the same compounds incorporating U238. The gaseous diffusion method was first utilized in the U.S. in the mid-1940s to provide enriched uranium compounds for military purposes. From the 1960s to the present, production of enriched uranium for commercial purposes in the U.S. has relied exclusively on this process. This process also has been utilized in other countries to produce enriched uranium.

1.3.1.2 Gas Centrifuge

Due to the substantial energy requirements of the gaseous diffusion process (approximately 50 times that of the gas centrifuge to be used at the CEC), the gas centrifuge process emerged in the 1970s as a viable enrichment alternative, although development had begun as early as the 1940s. In the centrifuge method, gaseous UF_6 is spun in a cylinder. The heavier compounds incorporating U238 are thrust against the outside wall of the cylinder while the lighter compounds incorporating U235 remain near the center of the cylinder. This method was originally demonstrated in the 1940s, but was not developed on a large scale because of problems associated with construction of efficient and reliable centrifuges. Significant gas centrifuge experience has been obtained in Europe by URENCO, the U.S. affiliate of which is a member of the LES partnership. URENCO operates three gas centrifuge enrichment plants, which are located in the United Kingdom, Germany, and The Netherlands. The CEC will be the first large-scale gas centrifuge enrichment plant operated in the U.S. Its enrichment system design is based exclusively on URENCO technology and experience.

1.3.1.3 Laser

An enrichment method with strong commercial potential for the future involves the use of a laser. The Atomic Vapor Laser Isotope Separation (AVLIS) process is currently being developed in the U.S. and in other countries. The feed material form is uranium metal. There is a potential for AVLIS to use existing stockpiles of depleted uranium from current enrichment facilities as plant feed after conversion from UF_6 to uranium metal.

1.3.1.4 Other Methods

Additional methods [illegible]

considered promising for commercial operation during the projected operating life of the CEC.

1.3.2 Uranium Hexafluoride

Uranium hexafluoride (UF_6) is the chemical compound of uranium used in both gaseous diffusion enrichment plants and in gas centrifuge enrichment plants. UF_6 is used because it is the only uranium compound that is a gas at ordinary temperatures and because fluorine only has one isotope (i.e., fluorine is monoisotopic). The advantage of fluorine being monoisotopic is that any weight variance between UF_6 molecules is due solely to the different isotopes of uranium. Almost fifty years of enrichment experience using UF_6 have proven that the material is especially suited for this application and for subsequent processing into nuclear fuel.

UF_6 is stored and transported in specially designed cylinders constructed of carbon steel. Specific design requirements are described in ANSI N14.1-1990 (Reference 8). All UF_6 cylinders handled at the CEC will be designed, built, and tested in accordance with this code. These cylinders are available in sizes that contain from 1/2 kg UF_6 to 12,500 kg UF_6. Depleted UF_6 (DUF_6) is normally stored in Type 48G (12,174 kg UF_6) and Type 48H (12,261 kg UF_6) cylinders. Other container types have been used in the past at various enrichment sites, however only 48-inch UF_6 cylinders in accordance with ANSI N14.1 will be used for storage and transport of DUF_6 at the CEC.

1.3.3 Depleted Uranium Hexafluoride

The enrichment process involves splitting a UF_6 feed stream into a product stream enriched in U235 and a by-product stream depleted in U235. The enriched product stream from the CEC will be used solely to fabricate fuel for commercial nuclear power plants. The by-product stream, commonly called "tails" material, consists of DUF_6 that still contains approximately 40% of its original U235. Approximately 5 to 10 kg of depleted uranium (DU) results from the production of 1 kg of low enriched uranium (LEU). Significant quantities of DU have been used in the U.S. in selected military and commercial applications. These include military projectiles, aircraft counterweights, and radiation shielding. Currently, the demand for this material is low.

The use of the term "tails" to describe DU is falling into disfavor. "Depleted uranium" more correctly describes the material without implying value of the material. This report uses the term "depleted uranium" (DU) except where quoting other sources.

1.3.4 Current Status

By the end of 1990, the tota. amount of DU in storage in the U.S. in the form of DUF_6 was approximately 320,000,000 kgU (kilograms of uranium, which does not include the additional mass of the fluorine). This material was produced by the U.S. Government in three gaseous diffusion enrichment plants. This amount is expected to grow by 20,000,000 kgU each year as the U.S. Department of Energy (DOE) continues to operate its gaseous diffusion plants (compared to 2,500,000 kgU per year for the CEC). Additional DUF_6 is stored worldwide, including 30,000,000 kgU stored by URENCO partners in Europe.

The current philosophy of the U.S. Government is to store DU as solid UF_6 in cylinders in specially designed outdoor storage yards. K/ETO-44, "The Ultimate Disposition of Depleted Uranium" (Reference 6) is a study performed by Martin Marietta Energy Systems, Inc. for the DOE, published in December of 1990. The study concludes that proper outdoor storage is safe and the most cost-effective method for DU management at DOE enrichment facilities at the present time.

1.3.5 Future Prospects

Refeed of the DU inventory through either the CEC or another uranium enrichment facility in the future is a promising possibility. The DOE has embarked on several major refeed campaigns in the past when there was a perceived shortage of DOE-owned natural uranium. Excess enrichment capacity would be well utilized by refeed to produce low-cost feed material. The advancement of enrichment technology with higher separative efficiency and lower operating costs also make refeed likely.

DU is a highly refined energy source that could be of significant value to future generations. Currently, the most promising long-term use for DU is as feedstock for fast breeder reactors. In breeder reactors, the energy contained in DU can be used in the form of both U235 and U238.

Non-nuclear uses of DU require that the material be converted to uranium metal. The current uses are limited to military applications and a few specialized civilian uses that require very dense material (uranium is 1.6 times as dense as lead), as discussed in Section 1.3.3.

The diverse potential uses of depleted uranium in the future require a utilization strategy which provides flexibility while ensuring safe handling and storage practices.

2.0 ANALYSIS BASES

2.1 CEC PHILOSOPHY

The technical and philosophical guidelines highlighted below were established by LES for the management of DUF_6 at the CEC. These guidelines are used as the basis for analyzing the options discussed in this report.

> **Utilization of DUF_6 is an effective strategy for environmental protection by reducing disposal requirements.**

LES is committed to operate the CEC in a manner which protects the environment. Utilization of DU reduces the amount of natural UF_6 required, reduces disposal requirements, effectively utilizes the DUF_6 as a resource, and thus minimizes the environmental impact.

> **Onsite storage and maintenance of DUF_6 cylinders shall not exceed the operational life of the facility.**

LES is committed to remove all radioactive materials from the CEC in accordance with NRC regulations during the CEC decommissioning. This criterion is unique to the CEC as compared to other uranium enrichment plants. The DOE, for example, is currently exempt from NRC regulation.

> **DUF_6 management must be consistent with existing laws and regulations pertaining to the handling, management, and disposal of DU and UF_6 while preserving the flexibility to adapt operational practices to future NRC and EPA policies and regulations.**

LES is committed to operate the CEC in accordance with applicable Federal, State, and Local laws and regulations. The current requirements that apply to LES and the CEC do not specifically cover the long-term management of DUF_6. Unique requirements may be promulgated specifically to address this aspect of plant operation. These requirements, if promulgated, would most likely be administered by the NRC and/or the EPA.

> **DUF_6 management must be protective of natural environmental components as well as human health and safety considerations.**

LES is committed to operate the CEC in such a manner that the environment around the plant is not adversely impacted. This commitment includes protection of the natural environment and

protection of the health and safety of people living in the area around the plant. LES is also committed to protecting the natural environment and the health and safety of people living in other areas. The overall impact of the options on all areas and people will be carefully evaluated to ensure that apparent safety improvements for the area surrounding the plant do not cause significant safety or environmental problems in other areas.

DUF_6 management must not result in a significant increase in risk to the health and safety of the public nor the environment compared to other relevant risks.

The currently accepted method for storage of DUF_6 at uranium enrichment plants is in specially designed cylinders stored outside. Options that significantly increase the risk compared to outside storage will not be implemented at the CEC. Careful evaluation of the options will be performed to ensure that there is no significant decrease in the margin of safety, considering both the area surrounding the plant and other areas which may be affected.

DUF_6 management must be consistent with commitments made to the local community and regulatory agencies.

LES is committed to open representation of the plant and its operation to the local community and to regulatory agencies. These agencies include Federal, State, and Local agencies that regulate LES and the CEC.

DUF_6 management must consider economic viability.

LES will operate the CEC in a sound long-term financial manner. This commitment is made to the owners and investors and also to the community around the plant. The plant will provide enrichment services to the electric utility industry at a fair price that will provide economic benefit to the plant owners, investors, employees, and neighbors. Funds will be set aside during each year of operation to provide for proper management of DUF_6 during decommissioning. Management techniques that increase overall costs without an appropriate improvement in safety or income potential impair LES' ability to be a long-term viable enterprise, and therefore, should be avoided.

2.2 LEGAL/REGULATORY REQUIREMENTS

This section summarizes the legal and regulatory requirements that apply to storage and disposal of DU. This section is based on the "Regulatory Analysis ... Depleted Uranium Stored at DOE PORTS

Facility" (Enclosure to Reference 10), and provides the basis for LES' position that DU is considered a resource and not a waste. As will be shown below, DUF_6 is source material and is not a hazardous waste subject to regulation under the Resource Conservation and Recovery Act of 1976 (RCRA).

2.2.1 Source Material

Depleted uranium is a "source material" subject to regulation under the Atomic Energy Act of 1954, as amended (AEA). Section 11(z) of the AEA [42 U.S.C. § 2014(z)] defines "source material" as follows:

> The term "source material" means (1) uranium, thorium, or any other material which is determined by the [Nuclear Regulatory] Commission pursuant to the provisions of Section 61 to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission may by regulation determine from time to time.

Section 61 of the AEA authorized the NRC to define the term "source material." The NRC promulgated the following regulatory definition in 10 CFR § 40.4:

> "Source Material" means: (1) Uranium or thorium, or any combination thereof, in any physical or chemical form or (2) ores which contain by weight one-twentieth of one percent (0.05 %) or more of: (i) Uranium, (ii) thorium, or (iii) any combination thereof. Source material does not include special nuclear material. (Emphasis added.)

The NRC further defined the term "depleted uranium" in 10 CFR § 40.4 as follows:

> "Depleted uranium" means the source material uranium in which the isotope uranium-235 is less than 0.711 weight percent of the total uranium present. Depleted uranium does not include special nuclear material.

Consistent with these definitions and DOE criteria (Reference 10), LES treats depleted uranium as source material.

2.2.2 Non-Hazardous Waste

Materials defined as "source material" under the AEA are not hazardous wastes. Under the federal system of regulation of hazardous waste, a material must first be defined as a "solid waste" before it may be regulated as a "hazardous waste" [42 U.S.C.

§ 6903(5)]. Section 1004(27) of the Resource Conservation and Recovery Act of 1976, as amended [42 U.S.C. § 6903(27)], excludes source material from the definition of "solid waste":

> The term "solid waste" . . . does not include . . . source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, as amended (68 Stat. 923)[42 U.S.C. § 2001 et seq.].

In regulations implementing the RCRA, the EPA states in 40 CFR § 261.4(a) the following exclusion:

> The following materials are not solid wastes for the purpose of this part:
>
> (4) Source, special nuclear or byproduct material as defined by the Atomic Energy Act of 1954, as amended, 42 U.S.C. § 2011 *et seq.*

To be considered a mixed waste, the DUF_6 would have to be mixed with a RCRA hazardous waste. Additional material (waste or otherwise) is not mixed with the UF_6 in the cylinders. Therefore, DUF_6 stored in ANSI N14.1 cylinders is not a mixed waste subject to regulation as a hazardous waste.

The EPA announced its mixed waste policy in the Federal Register on July 3, 1986 (51 FR 24504). That policy and subsequent clarifications issued by the EPA indicate that the EPA intended to regulate as "mixed wastes" those radioactive materials that become mixed with a non-AEA material that is a hazardous waste. Radioactive materials such as DUF_6 that have not been mixed with a non-AEA material that is a hazardous waste are not considered "mixed wastes" regulated by RCRA. See "Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste" (52 FR 11147) for a complete description of this topic.

2.2.3 Conclusion

DUF_6 is defined as "source material" and is exempt from regulation under RCRA under current regulations. In addition to this legal interpretation, the material has numerous potential nuclear and non-nuclear uses that are described in Section 3.1.2. This is consistent with the Reference 6 conclusion that under existing laws and regulations, DOE is free to manage the DU resource for the benefit of its uranium enrichment program.

2.3 WASTE TYPE COMPARISON

The DUF_6 produced at the CEC is considered a resource. However, if in the future it is no longer considered usable, the waste type must be defined prior to a disposal route being determined. DUF_6 is not a suitable form for disposal in accordance with 10 CFR § 61.56(a), and would require conversion to UF_4, a uranium oxide, or uranium metal prior to disposal. Under 10 CFR § 61.58, the NRC may authorize specific provisions for the classification and characteristics of waste, on a specific basis. This will be the case if, after evaluation of specific characteristics of the waste, disposal site, and method of disposal, the NRC finds reasonable assurance of compliance with the performance objectives of Subpart C of Part 61. Comparisons of DU to high-level radioactive waste (HLW), uranium mill tailings, and low-level radioactive waste (LLW) can provide insight into alternate disposal options.

2.3.1 High-Level Radioactive Waste (HLW)

HLW by definition (10 CFR § 60.2), is: (1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted. These wastes contain large quantities of long and short lived radionuclides and transuranics (TRU) with very high levels of activity.

An example of HLW is spent fuel, which constitutes approximately 35 m^3 of waste per reactor-year, with activity levels of 11,000,000 curies (after 10 years in the fuel pool) or approximately 300,000 Ci/m^3. In comparison, depleted uranium from the enrichment process in the form of U_3O_8 has an activity level of about 0.31 µCi/g, which equates to approximately 62 curies of activity for the 200 metric tons of uranium (MTU) of depleted uranium resulting per reactor-year. This is about 2 Ci/m^3 for the uranium isotopes, or about 5 Ci/m^3, including the Th234 and Pa234 decay daughters. Thus, the specific activity of spent fuel HLW is approximately 100,000 times greater than U_3O_8 from DU. Ingrowth of other decay products is extremely slow, requiring tens of thousands of years. This discussion assumes that no recycled uranium is involved as the CEC will not use such material.

Based on the definition of HLW from 10 CFR § 60.2 and the comparison of a typical HLW with DU above, it is clear that DU is not HLW.

2.3.2 Uranium Mill Tailings

Uranium mill tailings result from the chemical processing of uranium ore to produce a uranium-rich U_3O_8 compound called "yellow cake." Section 101(8) of the Uranium Mill Tailings Radiation Control Act of 1978, as amended [42 U.S.C. § 7911(8)], defines "tailings" as: the remaining portion of a metal-bearing ore after some or all of such metal, such as uranium, has been extracted. The principal radionuclides in the mill tailings are uranium, Ra226 and its decay products, and Th230. However, radium and its decay products, especially gaseous Radon, constitute the activity of concern, since most of the uranium is removed in the milling process. Thus, uranium radioactivity levels in the mill tailings are substantially less than the radium radioactivity levels. For example, long-lived uranium activity level in mill tailings is approximately 25 pCi/g, whereas the Ra226 level averages 450 pCi/g, with a half-life of 1,600 years. However, the low uranium content of the ore processed in the mill, the extraction of the uranium, and finally, clean-up of the mill sites, produces large quantities of wastes that are mainly comprised of soil and crushed rock plus process chemicals.

DU in the form of U_3O_8 is similar to mill tailings in that it contains uranium, but dissimilar in that DU is essentially free of Th230 or Ra226 and its decay products. DU which has been converted to U_3O_8 also differs from mill tailings in that it is concentrated U_3O_8 rather than large quantities of soil mixed with small quantities of radioactive material as with mill tailings.

2.3.3 Low-Level Radioactive Waste (LLW)

LLW contains a relatively small amount of radioactivity and constitutes the majority of the wastes generated by the commercial nuclear power plant fuel cycle. As defined by 42 U.S.C. § 2021b(9), "low-level radioactive waste" means radioactive material that - (A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material (as defined in section 2014(e)(2) of this title); and (B) the Nuclear Regulatory Commission, consistent with existing law and in accordance with paragraph (A), classifies as low-level radioactive waste.

Although long-lived isotopes of uranium, thorium, and low concentrations of TRU and other long-lived radionuclides can be present in LLW, the bulk of the radioactivity results from Co60, Cs134, Cs137, and other lower-yield fission and activation products with maximum half-lives of approximately 30 years. LLW decays to very low radioactivity levels in tens to hundreds of years, but it requires isolation during that time. DU is different from most LLW in that it contains only the long-lived isotopes of uranium in concentrated form, plus Th234 and Pa234. However, in accordance

with 10 CFR Parts 40 and 61, DU from the enrichment process is source material.

If DU is declared to be waste, it can be included within the definition of LLW, and could be disposed of in a LLW disposal facility licensed under 10 CFR Part 61 if it is in a proper waste form. Because the NRC did not consider the disposal of large quantities of DU when it promulgated the regulation, additional review by the NRC will be necessary. Under current 10 CFR § 61.55(a), stable DU compounds are a Class A waste. However, DUF_6 in ANSI N14.1 cylinders is not an acceptable waste form as required by 10 CFR § 61.56(a). DU can currently be disposed of either in the form of UF_4 or one of the oxides. The dry material would be transported and buried in appropriately lined steel drums, since these materials are only slightly soluble in water. Uranium metal can also be disposed of as LLW but has the additional advantage of not being soluble in water although it is pyrophoric.

2.3.4 Conclusion

DU requiring disposal will probably require conversion to UF_4 or U_3O_8 for disposal at a low-level radioactive waste facility.

2.4 RISK ANALYSIS METHODOLOGY

In order to evaluate the relative risks associated with the different management options, the scope of the analysis must be defined. This section outlines the important topics considered for this options analysis. The analysis encompassed all aspects of each management option and was not limited to the CEC and the surrounding area. The purpose of this large-scale review was to ensure that risks were controlled and minimized instead of only relocated.

The natural environmental components of the analysis consisted of the following:

- Land Resources (Geology, Soils, Minerals)
- Water Resources (Hydrology, Water Quality)
- Air Resources (Meteorology, Air Quality, Emissions)
- Biological Resources (Plant and Animal Communities)
- Material Resources (Fuels, Non-Fuels)
- Waste Generation (Liquid, Solid, Gaseous)

The human health and safety components of the analysis consisted of the following:

- Cylinder Handling Events
- Cylinder Transportation
- Processing Events
- Chemical/Radiological Exposures
- Occupational Events & Situations

The economic and the cost/benefit component of the analysis consisted of the following:

- Capital (Construction, Operation and Maintenance) Expenditures (Storage vs. Conversion Facilities)
- Value of Products/By-Products (Storage vs. Conversion)
- Short and Long-Term Economics (Present vs. Future) and Expenditures (Storage vs. Conversion)
- Inspection, Surveillance and Maintenance Program Costs (Storage vs. Conversion)

2.5 U.S. DEPARTMENT OF ENERGY

Future DOE action with regard to DU management and disposition will affect the regulatory and economic environment in which the CEC exists and might significantly affect the CEC DUF_6 management philosophy. If, for example, the DOE decides to convert its inventory of DUF_6 to U_3O_8, it could become commercially attractive for an investor to build a facility in the U.S. to perform such a conversion. The price of this conversion process might then cause it to become the preferred option due to the economics of a large-scale operation, which in turn could affect which option is prudent for LES to adopt.

2.6 MAJOR ASSUMPTIONS

Following are the major assumptions on which the analysis in Section 3.0 is based:

1. The first period analyzed is the operating life of the CEC in which DUF_6 is continually being generated. This is assumed to be from the initial receipt of UF_6 in 1995 to the expiration of the operational portion of the license in 2023. 300 cylinders of DUF_6 are assumed per year.

2. The second period analyzed is the decommissioning of the CEC where any DUF_6 remaining at the site must be removed. This is assumed to be the time period from 2023 to 2028.

3. The DOE uranium enrichment facilities will continue to operate for the life of the CEC.

4. No onsite conversion at the CEC of DUF_6 to other forms is considered.

3.0 DUF_6 OPTION ANALYSIS

The analyses that form the basis for this report cover two time periods. The first period is the operating life of the CEC in which DUF_6 is continually being generated. The second period is the decommissioning of the CEC where any DUF_6 remaining at the site must be removed. All options were analyzed to ensure that they met the criteria described in Section 2.0. The options that met these criteria and were further analyzed are listed below. Cost comparisons are provided in Appendix E.

I. DUF_6 Management Options During CEC Operation

A. Storage until decommissioning

1. Onsite at the CEC
   - A) Outdoors
     - 1) as UF_6
     - 2) as UF_4
     - 3) as uranium oxide
     - 4) as uranium metal
   - B) Indoors
     - 1) as UF_6
     - 2) as UF_4
     - 3) as uranium oxide
     - 4) as uranium metal

2. Away from the CEC
   - A) DUF_6 at DOE facilities
   - B) Retrievable storage
     - 1) as UF_4
     - 2) as uranium oxide
     - 3) as uranium metal

B. Utilization

1. Nuclear uses
   - A) Refeed for existing enrichment plants
   - B) Fast breeder reactor fuel
   - C) Laser enrichment (AVLIS) feed

2. Non-nuclear uses

C. Disposal of DU as it is generated

1. As UF_4
2. As uranium oxide
3. As uranium metal

II. DUF_6 Management Options During CEC Decommissioning

A. Transfer material and ownership
   1. DOE enrichment plant
   2. Other

B. Retrievable long-term storage
   1. As UF_6
   2. As uranium oxide
   3. As uranium metal

C. Disposal
   1. As UF_6
   2. As uranium oxide
   3. As uranium metal

3.1 DUF_6 MANAGEMENT OPTIONS DURING CEC OPERATION

The following sections describe the analysis of each of the options listed above for DUF_6 management during operation of the CEC.

3.1.1 Storage

Storage of DUF_6 at the enrichment plant is the current DU management philosophy for all operators of uranium enrichment plants except for the French. The French deviate partially from this philosophy, converting a portion of their DUF_6 to U_3O_8 due to government regulations limiting storage capacity. Storage of DU until decommissioning of the CEC provides the most flexibility for LES for the ultimate disposition of the material. This option preserves the utilization option as the disposition method until around 2025. This option maximizes the time available for markets to develop to prevent the resource from being wasted. Several different storage options are available and are described in the following sections.

3.1.1.1 Onsite Storage as UF_6

The method currently used by the DOE for storage of DUF_6 from their gaseous diffusion enrichment plants is outside storage in the form of solid UF_6 in specially designed steel cylinders. This method has been used by the DOE for forty years. The DOE estimated that at the end of FY 1990 it had over 40,000 DUF_6 cylinders in storage at its three diffusion plant sites. The estimated safe life of ANSI N14.1 cylinders is more than twice the operating life of the CEC. Properly coated cylinders are estimated to need recoating an average of no more than once during their life at the CEC. Most would not need an additional coating at any time during storage at

the CEC. The requirements necessary for proper outside storage are described in Appendix B.

Storage onsite as UF_6 allows for easy utilization as feed material for uranium enrichment plants, including the CEC. See Appendix C for a discussion of the basis for refeeding. The refeeding option is an important economic consideration if there is unused capacity at the CEC.

The capital cost for this option is inherently low because of the large number of UF_6 cylinders purchased worldwide for this purpose. Special storage yards are required but they do not require sophisticated engineering or construction techniques.

Storage onsite minimizes the amount of handling and transportation of the UF_6 cylinders. While the risks associated with these activities are extremely low, unnecessary handling and transportation should be avoided.

A disadvantage of UF_6 is that the material is reactive and unstable in the presence of water. It also can sublime at normal temperatures and pressures even though it is stored only in solid form. The cylinders perform an important safety function for containing the material and must be periodically inspected and maintained. The risks associated with the storage of DUF_6 in cylinders onsite has been fully addressed in the CEC Safety Analysis Report (Reference 2). Section 2.4 of the CEC Safety Analysis Report evaluates all accident scenarios involving leaking and ruptured UF_6 cylinders and concludes that any such accident to cylinders in storage would not result in a significant potential for offsite exposures.

3.1.1.2 Onsite Storage as UF_4

An optional DU storage method at the CEC is in the form of UF_4. This material is much less reactive than UF_6 and is only slightly soluble in water. UF_4 cannot sublime at normal temperatures and pressures. These factors allow the material to be stored in simpler containers which also simplifies the container maintenance and inspection requirements. Storage of the material in this form is a well-proven process for non-depleted uranium at uranium conversion facilities in preparation for the manufacture of natural UF_6. The containers for storage of this material are currently available and are of a well-proven design.

Facilities for the conversion of DUF_6 to DUF_4 are currently operating in the U.S. with adequate capacity for processing the material generated by the CEC. See Appendix B for a complete description of the conversion process.

Conversion to DUF_4 would prevent the direct utilization of the material as refeed material for the CEC or another uranium enrichment plant. An additional conversion process would be required for utilization in this manner. Currently, DUF_4 is an acceptable form for disposal in a Low-Level Radioactive Waste Disposal Facility.

The density of packaged DUF_4 is only slightly less than that of UF_6. Therefore, the required size of the DU storage area at the CEC would not be significantly reduced.

The conversion costs for this process are currently reasonable but would be wasted if the material was either needed for refeed or if disposal regulations changed to favor a different chemical form.

Conversion to UF_4 for storage involves additional facilities, chemical processes (including handling and storage of toxic HF), and transportation that each entail their own risks, however slight. Cumulatively, these risks are greater than those associated with onsite storage as DUF_6 in cylinders. Thus, there would be a slight reduction in overall safety with conversion to UF_4 compared to storage as UF_6.

3.1.1.3 Onsite Storage as Uranium Oxide

Another optional DU storage form is to convert the DU to one of the uranium oxides. These oxides include triuranium octoxide (U_3O_8), uranium dioxide (UO_2), and uranium trioxide (UO_3). The uranium oxides are a stable group of compounds that are not soluble in water. These compounds, especially U_3O_8, are well suited for long-term storage or disposal. The French currently convert a portion of the DUF_6 generated by the Eurodif plant to U_3O_8 for long-term retrievable storage.

U_3O_8 is the preferred uranium oxide for long-term storage or disposal. UO_3 is more difficult to produce in the pure form and will hydrolyze in air at ambient temperatures. UO_2 is the chemical form used for power reactor fuel, but powdered UO_2 must be stabilized to prevent reaction with oxygen in air, producing U_3O_8.

Facilities are currently unavailable in the U.S. to perform the conversion of DUF_6 to U_3O_8. The conversion process of DUF_6 to uranium oxides is comparable to the conversion of enriched UF_6 to UO_2, a well-proven process that is used extensively in fuel manufacturing in the U.S. and various countries abroad. The conversion process is described in Appendix D.

COGEMA in France is capable of performing the conversion process for LES. However, a potential conflict of interest (COGEMA is a potential competitor with LES for enrichment services) and shipping

costs to and from France make this option uncertain. Also, additional capacity is not available to accommodate the CEC DU.

Conversion would prevent utilization of the material as refeed for an enrichment plant without additional conversion steps. Additional conversion steps would not be necessary for future disposal. The uranium oxides have characteristics that make them well-suited for most methods of disposal with U_3O_8 the preferred material.

The storage area required for the uranium oxides can be half the size necessary for UF_6 storage. The maintenance and inspection requirements also would be less than those required for either UF_6 or UF_4 due to its stability and insolubility. Inspection would still be necessary to ensure that the containers remain intact and maintenance would be performed as necessary

The current cost to convert DUF_6 to U_3O_8 is uncertain since there are no available facilities in the U.S. Changes in the practices of other enrichment facilities may provide a competitive market for this service. Conversion to an oxide could become competitive with conversion to UF_4 if there is a market for the recovered fluorine (as HF). If there is no market, it could become a low-level radioactive waste that would require treatment prior to disposal. Handling of HF also entails risks because it is corrosive and toxic.

Conversion to uranium oxide for storage involves additional facilities, chemical processes, and transportation that each entail their own risks, however slight. A safety improvement is not obvious for conversion to uranium oxide as compared to storage as UF_6.

3.1.1.4 Onsite Storage as Uranium Metal

The final optional form for the storage of DU at the CEC is as uranium metal. Uranium metal is stable and insoluble in water though exposure to the elements will result in surface oxidation. Uranium metal is the most dense form for storage of DU and requires only simple containers. A substantial reduction in the size of the DU storage area at the CEC would be possible, but the actual storage requirements would depend on the anticipated final disposition of the material. Outside storage would only be acceptable if the ingots were coated to minimize oxidation and prevent migration of any uranium oxide that may be formed.

Uranium metal is easily utilized as either feed for a future AVLIS enrichment plant or as a high density material (i.e. projectile, shielding material, [illegible]). However, the uranium

metal would not be suited for refeed to the CEC without conversion back to UF_6.

The cost of conversion to uranium metal is approximately 3 times that of other conversion forms. The high cost of this conversion option is prohibitive unless the uranium metal can be utilized as described above. See Appendix E for the cost analysis.

Facilities are currently operating in the U.S. for the conversion of DUF_6 to uranium metal. Adequate capacity is also available but the conversion costs are significantly higher than for the conversion of UF_6 to UF_4. The conversion process also results in a significant solid waste stream (MgF_2) that requires disposal in a Low-Level Radioactive Waste Facility. The recovery and reuse of fluorine also affects the cost of the conversion process. If reuse of the fluorine is not possible, it also becomes a waste that requires disposal. See Appendix D for a detailed description of the conversion process.

Conversion to uranium metal for storage involves additional facilities, chemical processes, and transportation that each entail their own risks, however slight. Cumulatively, these risks are greater than those associated with onsite storage as DUF_6 in cylinders. Thus, there would be a slight reduction in overall safety with conversion to uranium metal compared to storage as UF_6.

3.1.1.5 Indoor Storage Versus Outdoor Storage

There are no current requirements for indoor storage of DU. This option was analyzed as an alternate to outdoor storage due to the potential for the reduction of maintenance costs during storage. The principal advantage of indoor storage at first sight is the prevention of continuous exposure of the cylinders to the elements. This would reduce the corrosion and extend the time between container maintenance, thus reducing the cylinder maintenance costs. No significant safety benefits would be realized from indoor storage of DU.

In order to benefit from indoor storage, a method of humidity control is required. Seasonal temperature changes can result in condensation of highly oxygenated (and thus highly corrosive) moisture on the container surfaces, resulting in higher corrosion rates than those encountered in outside storage with free air exchange. Effective indoor storage requires the control of relative humidity to less than 50%. In Louisiana this would require some level of temperature control as well.

Indoor storage only has significant advantages for UF_6 and uranium metal. Indoor storage of UF_6, with environmental controls, improves the life of UF_6 cylinders which are important for the

containment of UF_6. Indoor storage of uranium metal reduces the rate of surface oxidation. Indoor storage of UF_4 and uranium oxide offers little advantage due to the relative unimportance of the containers.

The capital cost of an indoor storage facility with environmental controls plus the cost of operating the environmental controls in Louisiana makes the total cost of indoor storage significantly higher than the total cost of outdoor storage, including the cost of cylinder maintenance. With proper maintenance of the cylinders outside in accordance with ANSI N14.1, no improvement in safety results from indoor storage.

3.1.1.6 Offsite Retrievable Storage

The final storage option is at a site other than the CEC, either converted to another form or as DUF_6. This option is practical only if there is a suitable site already storing similar material. The options for offsite storage locations are:

1. DOE-owned uranium enrichment plants.

2. Commercial waste storage facilities.

Storage in the form of UF_6 at another uranium enrichment plant would result in an insignificant improvement in safety at the CEC. The increased handling and the additional transportation of the UF_6 cylinders would entail their own risks, and result in a reduction in safety for the overall U.S. population.

Regulatory problems may prevent the storage of DU at a commercial waste storage facility if the material is not a waste. This option may also preclude any refeed or utilization options. Currently, there are no waste storage facilities in the U.S. capable of storing the quantity of DU that will be produced by the CEC.

The overall cost for storing the material at a commercial waste storage facility is higher than storage at the CEC. Storage at another enrichment facility would inherently have the same costs as storage at the CEC. Transportation costs for moving the material from the CEC to another site would add to this cost and add additional risks, however minimal.

Any form of offsite storage would not necessarily relieve LES of liability for the material.

3.1.1.7 Storage Options Conclusion

Outdoor storage of DUF_6 at the CEC is the best storage option, based on the following:

1. Much lower cost, without increased safety risk, than indoor storage with environmental controls.

2. Decreased cost and less handling risk, than offsite storage.

3. Option retained for future utilization with resulting decrease in waste inventory and lower cost. These options would be lost or reduced by converting to UF_4, uranium oxide, or uranium metal.

4. Option of refeed in existing or future higher efficiency enrichment facilities.

5. Lower cost, and decreased handling and processing risks than conversion to other forms.

The only credible disadvantage of UF_6 storage is the reaction with water in the event of a cylinder leak. Forty years of successful UF_6 storage experience, proper cylinder maintenance, and the fact that the internal UF_6 pressure is less than atmospheric minimize this risk.

Conversion of a portion of the UF_6 to U_3O_8 may become a viable option if facilities become available in the U.S. U_3O_8 is well-suited for long-term storage and disposal and allows for fluorine recovery.

3.1.2 Utilization

The most desirable option for DU management is utilization of the material as an energy source. A substantial amount of energy is contained in DU currently in storage at the uranium enrichment plants in the world. This energy is unused because the cost to extract the remaining energy is greater than the cost to extract that same amount of energy from natural UF_6 for conventional plants, and because breeder reactor technology is not yet available. If the cost of new feed material increases, the cost of enrichment decreases, or alternate energy conversion processes emerge (e.g., breeder reactor), this material could be utilized if retained in a suitable form.

The amount of DU to be disposed of as waste is reduced by the amount utilized, thereby reducing disposal costs. The actual reduction depends on the method of utilization. For example, utilization of the DUF_6 as refeed to a uranium enrichment facility

results in a very small reduction of DUF_6 in itself, with a majority of the material still requiring utilization in another manner or disposal. However, refeed replaces natural feed that would produce additional DUF_6. Alternatively, the utilization of DU as fuel or as a metal results in the complete utilization of the material.

Utilization of uranium metal recovered from DUF_6 is currently performed at two facilities in the U.S. Most of the metal is used by the military in a non-nuclear application for projectiles, but there are additional civilian uses for the uranium metal.

Current utilization rates of DU are substantially less than the U.S. production rate. Specific projections are difficult to make for the use of the material during the time frame involved. Short-term utilization of significant quantities of DU is not likely but there is high probability that at least one of the long-term utilization options will be commercialized during the life of the CEC.

Utilization of previously discarded by-products has been greatly expanded throughout industry in the past 20-30 years and is expected to continue. Appropriate storage as UF_6 will allow this option to be retained as technology advances.

3.1.2.1 CEC Feed Material

A likely use for DUF_6 generated by the CEC is refeed of the material through a uranium enrichment plant. The plant may be the CEC, a similar plant, or an advanced uranium enrichment plant. The U235 assay of DUF_6 is determined by economics of the enrichment industry. The variables in this economic analysis are the cost of natural UF_6 and the cost to operate the enrichment plant. Higher costs for natural UF_6 (i.e., increase in uranium costs) or lower processing costs (i.e., advanced enrichment techniques) would make DUF_6 from the CEC an attractive feed material. See Appendix C for a detailed discussion of the economics. It should be noted that refeeding DUF_6 in itself only reduces the quantity of DUF_6 by a few percent, but refeed does reduce the total amount of UF_6 (and its resulting DUF_6) needed by a substantial amount by replacing natural UF_6 feed.

The operating plan for the CEC is to operate the plant using natural UF_6 as feed material and to operate at full capacity. At current feed material and operating costs, it is not economical to feed DUF_6 into the CEC because of the reduced product output flow. A dramatic increase in the cost of natural UF_6 or a shortage of UF_6 may make DUF_6 an attractive feed option.

Enrichment capacity above that required to meet contract commitments could make it attractive to enrich DUF_6 to a U235 assay of 0.711% to sell or utilize as feed material in place of natural UF_6.

3.1.2.2 Fast Breeder Reactor Feedstock

The U238 isotope in DU can be placed in a fast breeder reactor core as a fertile material. The U238 is irradiated and, after absorbing a neutron and undergoing beta decay, becomes Pu239. Pu239 is a fissile material, some is burned in place, the rest can be used as breeder reactor fuel.

The DOE breeder reactor development programs in the U.S. are General Electric's Power Reactor Inherently Safe Module (PRISM) and Argonne National Laboratories' Integral Fast Reactor (IFR). The French, Soviets, and Japanese are also developing breeder reactor programs. These programs may represent a significant energy resource for the next century.

3.1.2.3 Feedstock For Laser Enrichment

Developing laser technology would allow for further stripping of the U235 isotope from the depleted UF_6. See Appendix C for a complete description of the economics of refeed. This would result in more complete utilization of the fissile U235 isotope in the UF_6 feed.

There is no current market for this application because the technology is not ready for commercial application. It is estimated that this technology will not be commercially available until after the year 2000. There is a very good chance that the CEC UF_6 can be used as feed for laser enrichment. However, due to the speculative nature of this option, it is not considered to be available.

3.1.2.4 Uranium Metal

Depleted uranium metal is currently manufactured commercially from DUF_6. Depleted uranium metal is approximately 1.6 times as dense as lead and exhibits high strength and mechanical properties. There are three principal uses of depleted uranium metal:

1. Armor-piercing projectiles for military ordnance
2. Radiation shielding
3. Aircraft counterweights

The largest U.S. consumer of DU in the past has been the military, in the form of specialized armor-piercing projectiles. In addition to high density, depleted uranium alloys offer high penetrator effectiveness and post penetration pyrophoricity. The Department of Defense Appropriations Act for FY 1991 requires that an additional 16,000,000 kgU be added to the national defense stockpile over the next 10 years. Reference 11 reports that the Air Force recently awarded a contract which will utilize approximately 2,000,000 kgU of depleted uranium for A-10 aircraft 30-mm cannon shells, which is the approximate amount of DUF_6 to be produced by the CEC per year. While current military needs do not constitute a major portion of the generation rate of DUF_6 at DOE facilities, they are comparable to the projected DU production of the CEC during the same period.

Depleted uranium metal is used in numerous types of medical and industrial radiography equipment to shield the user and patients from high levels of radiation. Because of its high density, depleted uranium metal is more effective than lead (per unit volume) for absorbing penetrating radiation. However, this use constitutes a very small fraction of the current generation rate of DUF_6.

Depleted uranium metal counterweights are used in airplanes, missiles and helicopters to maintain center of gravity when control surfaces are moved. High density is important in order to keep the counterweight small in confined spaces. Again, this use constitutes a very small fraction of the current generation rate of DUF_6.

Demand for uranium metal is expected to continue through the life of the CEC, but only at a fraction of the supply of DUF_6. Conversion to uranium metal should be continued to the extent demand warrants.

3.1.3 Disposal of UF_6 as it is Generated

Another option is to dispose of the DUF_6 as it is generated. This option would replace the large DUF_6 storage yard with a small buffer storage yard for the storage of about 150 DUF_6 cylinders. This would allow for as little as two annual shipments from the CEC. All material would be converted offsite to either UF_4, uranium oxide, or uranium metal for disposal. See Section 3.2.3 for a description of the disposal material options. Currently, the only feasible disposal option is the conversion to UF_4.

The cost for storage and maintenance of the DUF_6 cylinders would be reduced. The cost of conversion of the material would be greater than the cost for conversion at decommissioning because the

production rate of the CEC would not be sufficient to allow for continuous operation of the conversion process.

The ability to utilize the DU for any future purpose would be lost with any type of immediate disposal option. Depending on the future value of the material, a sizable economic loss may be suffered by LES with this option with no benefit. Furthermore, the amount of total waste disposal required may be increased along with its inherent risk and cost.

3.2 DUF$_6$ MANAGEMENT OPTIONS DURING CEC DECOMMISSIONING

Currently, commercial and government demands for DU consume only a fraction of the material produced by uranium enrichment facilities. Even complete depletion of the U235 contained in the DUF$_6$ will result in material for disposition during the decommissioning of the CEC. The following sections review the options available for permanent disposition of DUF$_6$ produced during the operational life of the CEC.

3.2.1 Transfer of Ownership

The most attractive option for final disposal of DUF$_6$ for LES is to transfer the ownership of the material and move it to another facility at the end of the operational life of the CEC in the form of UF$_6$. No processing or disposal costs would be incurred. This option would be attractive provided there is not a commercial utilization process available at the time the material must be removed from the CEC site but near-term commercialization is anticipated.

The most likely party to agree to be a recipient of the CEC DUF$_6$ in the U.S. is the DOE, which is the most likely operator of a U.S. advanced enrichment plant. Another possible recipient for the material is a breeder reactor program. Such programs are under development in the U.S. and in other countries (See Section 3.1.2.2).

Concrete plans cannot be made and all options envisioned for ownership transfer and movement thirty years in the future. Current management policies should be established that keep such options open as long as possible to maximize the possibility of utilization.

3.2.2 Retrievable Long-Term Storage Offsite

Long-term retrievable storage is also an option to allow for future utilization of DU. The DOE is the most likely organization to provide this type of storage. The DOE currently has substantially

more DUF_6 in long-term storage than the CEC will produce in its operational life. The final disposition of the material could then wait for a national policy for long-term DU management. Specific legal questions would have to address the liability of LES for the material during storage.

The specific form for storage of the material would depend on the location and the method of storage. The same advantages and disadvantages for conversion to UF_4, uranium oxide, and uranium metal described in Section 3.1.1 for onsite storage apply to this option.

3.2.3 Disposal

Another option for DUF_6 disposition is conversion to a stable chemical form and disposal as low-level waste. This could be necessary if none of the other options described in Section 3.2 are possible. This option is considered only because of the LES commitment to remove all DU from the CEC site at decommissioning. This option should not be the preferred long-term national policy for DU management.

Uranium hexafluoride is not an acceptable form for disposal of DU. UF_6 is highly reactive with water forming two compounds, hydrogen fluoride (HF) and uranyl fluoride (UO_2F_2). HF is an acidic gas that can cause burns of the skin and lungs if it is concentrated. UO_2F_2 is a uranium compound that is highly soluble in water. These two compounds are also not acceptable forms for disposal. Chemical conversion to a stable form would be required prior to disposal. The available options are conversion to a uranium oxide, to uranium tetrafluoride, or to uranium metal. See Appendix D for a description of the conversion processes.

Currently, the disposition options are limited. See Section 2.3 for a discussion on waste type determination. The most likely disposal options are burial in a Low-Level Radioactive Waste Facility or burial in some unique facility. One such facility is the Dawn Mining Company uranium millsite in Washington. The site is accepting very low level radioactive fill for remediation of a below-ground mill tailings impoundment. DUF_6 would require conversion to a stable material such as UF_4 or a uranium oxide with an activity level below the level required by the disposal site. Such sites almost certainly will be available at the time of CEC decommissioning.

Low-level radioactive waste from the CEC will be handled by the Central States Low-Level Waste Compact. From 1993 until 2012 the state of Nebraska is projected to host the disposal site. In 2013 another state in the compact will host the site. It is not possible now to anticipate the exact regulations that will cover DU

disposal in the future. However, it is not unreasonable to expect that appropriately packaged DU as DUF_4 or U_3O_8 would meet any reasonable acceptance criteria established for Low-Level Waste Compacts. Periodic review of the current and future regulations will be performed by LES to ensure that the disposal costs allocated for decommissioning are correct.

4.0 CONCLUSIONS

The following conclusions are reached based on the analysis in Section 3.0:

1. DUF_4 is an energy resource with additional non-energy related uses. As such it should, wherever possible without increasing the risk to the public or the environment, be maintained in a useable, or at least retrievable, form in the interest of future generations.

2. Outdoor DUF_4 storage at the CEC is safe and is the most economical option for DU management by LES. This option maximizes the possibility of future utilization or ownership transfer which will minimize the disposition cost to LES.

3. Storage onsite as UF_6, uranium oxide, or uranium metal offers no improvement in overall safety or cost compared to storage as DUF_4 in cylinders which would justify conversion.

4. Offsite storage only adds to the total management cost and handling risk with no improvement in overall safety.

5. Disposal of DU as it is generated only adds to the total management cost with no significant improvement in safety, while eliminating the possibility for cost savings and waste reduction through utilization.

6. The cost basis for long-term disposition is conversion of DUF_4 to DUF_6 and disposal at a Low-Level Radioactive Waste Facility. This option is available currently and allocating funds to cover these anticipated costs ensures that the means for disposition of the material will be available at decommissioning.

7. Ownership transfer and movement offsite for use by a breeder reactor program or an advanced enrichment program provide the best option for future utilization of the energy potential contained in DU.

5.0 RECOMMENDATIONS

The following recommendations are provided based on this study:

1. LES should store DU at the CEC in the form of DUF_6 until utilized or until the end of the operational life of the CEC. DUF_6 storage onsite should meet all of the guidelines outlined in Section 2.1.

2. DUF_6 storage should meet all of the UF_6 cylinder storage requirements outlined in Appendix B.

3. LES should refeed DUF_6 to the maximum extent economically possible to reduce the amount of natural feed material that is required. Excess capacity could be used to produce natural feed from DUF_6.

4. LES should support DU utilization for both nuclear and non-nuclear uses. This utilization provides the best alternative to minimize disposal costs.

5. LES should remain informed of related industry developments and programs (i.e., DOE, other enrichment facilities, and breeder reactor programs) to ensure that the CEC long-term DU management plan promotes complete and efficient utilization of the DU resource.

6. LES should work closely with the NRC, DOE, and the commercial sector, who provide appropriate regulations and facilities, to ensure the maximum practical utilization of depleted uranium as a resource and for the safe and economic disposal of DU if and when it is ultimately declared unusable.

7. LES will ensure that appropriate financing is available to remove all DU from the CEC and provide for its disposition at decommissioning. LES currently uses DUF_6 conversion to UF_6 and burial at a Low-Level Radioactive Waste Facility as the cost basis for this financing plan. LES should review the plan every five years to ensure that the plan remains adequate.

6.0 REFERENCES

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APPENDIX A

NOMENCLATURE

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NOMENCLATURE

Below is a list of the terms, abbreviations, and acronyms used in this report.

ANSI - American National Standards Institute

AVLIS - Atomic Vapor Laser Isotope Separation

BETA - Break-even Tails Assay

CEC - Claiborne Enrichment Center

COGEMA - Compagnie General de Matirere Atomique - A French company that provides nuclear fuel cycle services

Co60 - Cobalt isotope 60

Cs134 - Cesium isotope 134

Cs137 - Cesium isotope 137

Depleted Uranium - Any uranium isotope mixture containing less than 0.711% U235

DOE - U.S. Department of Energy

DU - Depleted uranium

DUF_6 - Depleted uranium hexafluoride

DUF_4 - Depleted uranium tetrafluoride

Feed Material - Uranium compounds specially formulated for introduction into a uranium enrichment facility

FR - Federal Register

FY - Fiscal year

Hazardous Waste - Wastes that contain materials listed by the EPA or exhibiting hazardous characteristics (non-radioactive)

HLW - High-level radioactive waste

IFR - Integral Fast Reactor

kg - Kilogram

kgU - Kilogram of uranium

LES - Louisiana Energy Services

LLW - Low-level radioactive waste

LEU - Low Enriched Uranium - Uranium containing between 0.711% and 20% U235

Mixed Waste - A waste that contains both radioactive material and hazardous material

MTU - Metric tons of uranium

NRC - U.S. Nuclear Regulatory Commission

Pa234 - Protactinium isotope 234

Pu239 - Plutonium isotope 239

PDU - Partially depleted uranium

PRISM - Power Reactor Inherently Safe Module

Product Material - Enriched uranium

Ra226 - Radium isotope 226

RCRA - Resource Conservation and Recovery Act of 1976

Tails Material - Depleted uranium

Th230 - Thorium isotope 230

Th234 - Thorium isotope 234

TRU - Transuranics

UF_4 - Uranium Tetrafluoride

UF_6 - Uranium Hexafluoride

U235 - Uranium isotope 235

U238 - Uranium isotope 238

APPENDIX B

UF_6 CYLINDER STORAGE REQUIREMENTS

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UF_6 CYLINDER STORAGE REQUIREMENTS

1. All DUF_6 shall be stored in 48X, 48Y, or 48G cylinders, which are fabricated, tested, and inspected in accordance with ANSI N14.1-1990.

2. All DUF_6 cylinders shall be stored in designated areas of the facility. These storage areas shall be segregated from the rest of the facility by barriers (e.g., vehicle guard rails).

3. All DUF_6 cylinders shall be stored on concrete saddles, or other saddles made of materials that do not cause corrosion of the cylinders. These saddles shall be placed on stable surfaces such as concrete or compacted gravel.

4. No stacking of cylinders shall be allowed. Storage array design shall permit easy visual inspection of all cylinders.

5. All DUF_6 cylinder valves shall be fitted with valve guards to protect the cylinder valve during transfer and storage.

6. Only designated vehicles shall be allowed in the DUF_6 storage yard.

7. Only trained and qualified personnel shall be allowed to operate vehicles in the DUF_6 storage yard.

8. All DUF_6 cylinders shall be abrasive blasted and coated with a minimum of one coat of zinc chromate primer plus one zinc-rich topcoat, or equivalent anti-corrosion treatment.

9. All DUF_6 cylinders shall be inspected for damage upon receipt at the facility and prior to placing a filled cylinder in the DUF_6 storage yard. All DUF_6 cylinders shall be reinspected annually for damage or surface coating defects. These inspections include inspections to verify that:

   A) Lifting points are free from distortion and cracking.

   B) Cylinder skirts and stiffener rings are free from distortion and cracking.

   C) Cylinder surfaces are free from bulges, dents, gouges, cracks or significant corrosion (e.g., rust).

D) Cylinder valves are fitted with the correct protector and cap, the valve is straight and not distorted, 2 to 6 threads are visible, and the square head of the valve stem is undamaged.

E) Cylinder plugs are undamaged and not leaking.

10. If inspection of a cylinder reveals significant deterioration, the contents of the cylinder shall be transferred to another cylinder, and the defective cylinder properly discarded.

11. Proper documentation on the status of each cylinder should be available on site, including information such as contents, inspection dates, etc.

APPENDIX C

TAILS ASSAY PHILOSOPHY

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TAILS ASSAY PHILOSOPHY

The economic objective for tails assay optimization is to minimize the overall cost of enriched uranium production by striking an optimum balance between feed and separative work costs. This balance is quantified as the optimum, or break-even, tails assay. The break-even tails assay (BETA) is a function of the ratio of the feed costs to the separative work costs and is completely independent of the enriched product assay.

At any given time, the optimum tails assay for an enrichment process can be calculated as described below based on the methodology of Appendix IV of Reference 6. The process will be operated so that the DU output is as close to this calculated BETA as possible. As feed and separative work costs change, the process is adjusted so that the output always remains close to the current BETA, within the operating range of the CEC.

Partially depleted uranium at any assay greater than the current BETA is a candidate for recycle as feed to an enrichment process to produce enriched product and DU at the current BETA. A significant improvement in the separative efficiency of the enrichment process also makes material from a less efficient enrichment plant attractive as refeed. DU at an assay less than or equal to the current BETA cannot be economically re-fed. The DU assay must in fact be a significant increment above the current BETA to make production costs attractive compared to that of natural feed.

The equation for calculating BETA is:

$$\frac{C_{Feed}}{C_{SWU}} = V(x_f) - V(x_w) - (x_f - x_w)\,(V'(x_w))$$

where:

C_{Feed} = *cost of feed in \$/kgU*
C_{SWU} = *cost of separative work in \$/kgSWU*
x_f = *feed assay in weight fraction U235*
x_w = *tails assay in weight fraction U235 (BETA)*

and where:

$$V(x) = (2x - 1)\left[\ln\left(\frac{x}{1 - x}\right)\right]$$

$$V'(x) = \left[\frac{2x - 1}{X(1 - x)}\right] + 2\ln\left(\frac{x}{1 - x}\right)$$

This set of equations condenses to:

$$\frac{C_{Feed}}{C_{SWU}} = (2x_f - 1)\ \ln\left[\frac{x_f(1 - x_w)}{x_w(1 - x_f)}\right] + \left(1 - \frac{x_f}{x_w}\right)\left(\frac{2x_w - 1}{1 - x_w}\right)$$

Note that for a given feed assay, the BETA is a function of the ratio of feed costs to separative work costs and is completely independent of the enriched product assay. Since the natural uranium feed assay is essentially a constant, BETA becomes a direct function of the desired feed-to-SWU cost ratio. This means that BETA is the same for any product assay and, if both feed and SWU costs increase by the same percentage (e.g., due to inflation), the BETA is unchanged.

The feed and SWU costs used should be the incremental costs that apply to the specific circumstances. Therefore, enrichment customers with different feed costs will have different optimum transaction tails assays. Plants of different design (e.g., gaseous diffusion vs. gas centrifuge vs. AVLIS) may have different incremental separative work costs so DU from one plant may be attractive as feed material to another plant with a different BETA. Likewise, the incremental production cost for LES is different from the cost to customers, so BETA for LES may be different, making recycle of DU into feed a possibility.

The above equation includes the proportional costs for DUF_6 storage and disposal. The effect of including the storage and disposal costs is to lower the BETA.

APPENDIX D

UF$_6$ CONVERSION PROCESS DESCRIPTIONS

APPENDIX D

UF_6 CONVERSION PROCESS DESCRIPTIONS

This appendix describes the basic elements of the various conversion processes for UF_6. All of the processes described are suitable for large-scale production but facilities may not be in existence or available in the U.S. to convert DUF_6 from the CEC.

A. CONVERSION TO A URANIUM OXIDE

Three uranium oxide compounds are suitable materials for disposal. These compounds are triuranium octoxide (U_3O_8), uranium dioxide (UO_2), and uranium trioxide (UO_3).

Any of the uranium oxides can be formed from UF_6 either by vapor-phase (dry) pyrohydrolysis-reduction or by dissolution in water followed by precipitation with a variety of reagents such as ammonia, ammonium carbonate, or hydrogen peroxide and then subsequent calcination of the collected precipitate. The process method and equipment selected depend on the product characteristics desired and the design of the HF by-product recovery system. Fluidized beds, rotary kilns, and screw reactors are used in the vapor phase process. In the wet process, filters and centrifuges collect precipitates, which may then be dried and calcined in screw or rotary kiln equipment.

Triuranium octoxide is also known as uranous-uranic oxide and uranyl uranate. It normally consists of olive green to black crystals or granules that are insoluble in water. Environmental, safety, and health issues favor U_3O_8 as the best-suited uranium compound for long-term storage or disposal. U_3O_8 is the most inert chemical form of uranium and therefore, has the lowest potential impact on people and the environment. U_3O_8 is insoluble even in weak acids and bases typically found in soil and groundwater. More details concerning risk characterizations of the alternate chemical forms of uranium can be found in Section 3.1.1.3.

U_3O_8 is formed by reacting UF_6 with superheated steam to form uranyl fluoride and hydrofluoric acid.

$$UF_6 + 2H_2O \Rightarrow UO_2F_2 + 4HF$$

The uranyl fluoride is then reacted with more superheated steam, sometimes augmented with hydrogen, at about 750°C to form the oxide plus hydrofluoric acid and oxygen.

$$6UO_2F_2 + 6H_2O \Rightarrow 2U_3O_8 + 12HF + O_2$$

and

$$3UO_2F_2 + 2H_2O + H_2 \Rightarrow U_3O_8 + 6HF$$

Conversion to other uranium oxide forms is also an option. UO_2 is normally in powder form, consisting of black crystals. UO_2 will ignite spontaneously in heated air and will slowly convert to U_3O_8 in air at ambient temperature. Its stability in air can be improved by sintering the powder in hydrogen. Uranium dioxide is formed by reacting UF_6 with steam and hydrogen to form uranyl fluoride, which is then converted to the desired oxide.

$$UF_6 + 2H_2O \Rightarrow UO_2F_2 + 4HF$$

$$UO_2F_2 + H_2 \Rightarrow UO_2 + 2HF$$

UO_2 can also be formed by conversion of UF_6 to UF_4 followed by conversion to the oxide. See Part B following for details of the UF_6-to-UF_4 conversion. The UF_4-to-oxide reaction is reversible so operating conditions must be carefully controlled to provide good yields.

$$UF_6 + H_2 \Rightarrow UF_4 + 2HF$$

and

$$UF_4 + 2H_2O \rightleftarrows UO_2 + 4HF$$

UO_2 normally consists of red-to yellow powders. UO_3 is difficult to produce in the pure form and will hydrolyze in air at ambient temperatures. UO_3 decomposes to U_3O_8 when heated. Both oxides, UO_3

and UO_3, are relatively stable chemically, noncorrosive, and resistant to leaching by groundwater.

An additional benefit of conversion to a uranium oxide is the recovery of fluorine as a byproduct. This recovery is an important economic consideration for the process because the recovered fluorine can be sold or reused, eliminating the disposal cost of the fluorine. The French have demonstrated the commercial feasibility of recovering fluorine, primarily as aqueous HF. However, the aqueous HF would likely be slightly contaminated with uranium and may not be marketable in this country. The most efficient way to utilize recovered HF would be in the conversion of natural uranium to UF_6 for feed to an enrichment plant. Uranium contamination would not be a concern in this process.

The HF collected from the conversion process that is not recycled can be neutralized with lime and dehydrated. The resultant calcium fluoride is then disposed of as a waste. The equation for this process is as follows:

$$2HF + Ca(OH)_2 \Rightarrow CaF_2 + 2H_2O$$

Currently, these oxide conversion processes are not commercially available in the U.S. for the conversion of DUF_6. All existing capacity is used for nuclear fuel fabrication. COGEMA currently operates an oxide conversion facility in France, converting a portion of their DUF_6 to U_3O_8.

B CONVERSION TO URANIUM TETRAFLUORIDE

Uranium tetrafluoride (UF_4) is also known as green salt. It normally consists of green crystals which are slightly corrosive and slightly soluble in water. The advantages that UF_4 offers are that it is an intermediate in existing processes for the production of uranium metal, the fraction of recovered HF is easily recycled in the UF_6 production process, commercial facilities exist in the U.S., and the cost of conversion is relatively low. A fully developed production process is already in use in an existing industry. Commercial facilities for converting UF_6 to UF_4 are currently in operation with installed capacities of more than 4,000 MTU/year. Reference 6 states that this capacity could be expanded to more than 25,000 MTU/year if market conditions were favorable.

Containers for storage of UF are currently in use, so development of new containers would not required. However, protection from the elements is essential for proper storage since UF_4 reacts slowly with moist air forming oxides and releasing corrosive HF.

The UF_6 to UF_4 reduction process reacts hydrogen with UF_6 in a tower reactor. The reaction becomes self-sustaining at approximately 800°F which is achieved either by heating the reactor wall or by injecting fluorine with the UF_6. Once ignited, the reaction proceeds vigorously and requires considerable cooling to maintain a wall temperature below 1000°F. The products are finely divided UF_4 powder and anhydrous HF. The equation for the reaction is as follows:

$$UF_6 + H_2 \Rightarrow UF_4 + 2HF$$

C. CONVERSION TO URANIUM METAL

The most compact storage form for DU is in the form of uranium metal. DU requires about 80% less storage space than DUF_4. Uranium metal is virtually insoluble in water but readily undergoes surface oxidation to U_3O_8. To prevent or minimize this oxidation, uranium metal placed in long-term storage would have to be given a protective coating.

The current UF_6-to-uranium metal conversion is a two-step operation that requires conversion to UF_4 as an intermediate step. The double conversion process consists of the initial UF_6-to-UF_4 conversion followed by a UF_4-to-uranium metal conversion which requires increased handling costs over the more direct conversion methods. Current U.S. conversion capacity is more that 8,000 MTU/year which is expandable to 12,000 MTU/year.

The current standard method for converting UF_6 to uranium metal is to first convert the UF_6 to UF_4 as described in Part B above. The finely powdered UF_4 is then reacted with magnesium in a batch reactor. The reactor and its contents are heated to between 550°C and 700°C to initiate the reaction. The reaction of the magnesium and uranium tetrafluoride yields uranium metal and magnesium fluoride. The equation for this reaction is as follows:

$$UF_6 + H_2 \Rightarrow UF_4 + 2HF$$

and

$$UF_4 + 2Mg \Rightarrow U + 2MgF_2$$

A by-product of this reaction is a large quantity of contaminated MgF_2 slag. This material requires disposal as low-level radioactive waste. This process also does not permit recovery of the majority of the fluorine present in the UF_6.

APPENDIX E

COST ANALYSIS

APPENDIX E

COST ANALYSIS

This appendix compares the costs of the UF_6 conversion options (i.e., UF_4, uranium oxide, and uranium metal). These cost estimates include transportation, conversion from UF_6, and disposal. The costs are on a annual basis, and are based on the projected yearly capacity of 300 UF_6 cylinders and current 1990 cost estimates from the uranium processing and waste disposal industries.

A. CONVERSION TO UF_4 AND DISPOSAL

Transportation Cost	$ 635,000
Cost of Conversion to UF_4	$ 10,600,000
Disposal Cost	$ 2,400,000
Total Cost:	**$ 13,635,000**

Conversion to UF_4, which is the majority of this cost, is anticipated to decrease by 20-50% based on a long-term contract, resulting in lower projected costs. This conversion and disposal method is currently available in the U.S. A 30% reduction was used for the $9.5 million per year estimate for disposition of UF_6 at decommissioning.

B. CONVERSION TO URANIUM METAL

Transportation Cost	$ 760,000
Cost of Conversion	$ 31,000,000
Disposal Cost	$ Not Avail.
Total Cost:	**$ 31,760,000** *

* Excluding disposal cost

This cost does not include disposal costs. A by-product of this conversion is contaminated MgF, slag, which requires disposal as low-level radioactive waste. This conversion

and disposal method is currently available in the U.S. Due to the extremely high cost and MgF_2 disposal, this conversion is only considered viable for the amount of uranium metal which can be utilized (See Section 3.1.2.4).

C. CONVERSION TO U_3O_8

Transportation Cost	$ 2,600,000	(1-way) *
Cost of Conversion to U_3O_8	$ 10,500,000	
Disposal Cost	$ N/A	*
Total Cost:	**$ 13,100,000**	

*. Assumes U_3O_8 is retained by COGEMA

These cost estimates are based on conversion of DUF_6 to U_3O_8 in France since these are the only facilities currently available. Due to the increased transportation costs, problems with shipment overseas, and the lack of additional capacity at these facilities, this option is uncertain.

U_3O_8 is well-suited for long-term storage and disposal. If facilities for converting UF_6 to U_3O_8 were to become available in the U.S., it is expected that the cost would be very attractive. To maintain this option requires storage as UF_6 until commercial facilities to convert UF_6 to U_3O_8 become available.