MODULE 7.0: Depleted Uranium

Introduction

Welcome to Module 7 of the Uranium Enrichment Processes Directed Self-Study Course! This is the seventh of seven modules available in this self-study course. This module provides an overview of Depleted Uranium Management including quantities, options, regulatory requirements, current activities, and NRC involvement.

This self-study module is designed to assist in accomplishing the learning objectives listed at the beginning of the module. The module has self-check questions and activities to help you assess your understanding of the concepts presented in the module.

Before You Begin

It is recommended that you have access to the following materials:

- ☐ Trainee Guide
- ☐ 10 CFR Part 76, “Certification of Gaseous Diffusion Plants”
- ☐ 10 CFR Part 70, “Domestic Licensing of Special Nuclear” Material

How to Complete this Module

1. Review the learning objectives.
2. Read each section within the module in sequential order.
3. Complete the self-check questions and activities.
4. Check off the tracking form as you complete the self-check questions and/or activities within the module.
5. Contact your administrator as prompted for a progress review meeting.
6. Contact your administrator as prompted for any additional materials and/or specific assignments.
7. Complete all assignments related to this module. If no other materials or assignments are given to you by your administrator, you have completed this module.
8. Ensure that you and your administrator have dated and initialed your progress on the tracking form.
9. Go to the next assigned module.

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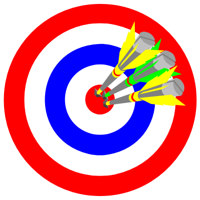


7.1 Describe situation/concerns with depleted uranium (DU) and potential disposition alternatives.

7.2 Describe the environmental, safety, and health (ES&H) aspects associated with depleted uranium management.

7.3 Describe DU disposition pathways including, storage, reuse, and disposal.

7.4 Discuss reuse scenarios in more detail. Many reuse applications rely upon the density of the DU form, with higher densities being preferred.

7.5 Describe the role DOE plays in depleted uranium management.

7.6 Describe the approach to depleted uranium management used outside the United States.

7.7 Discuss the NRC's involvement in depleted uranium management in the future.

Learning Objective

When you finish this section, you will be able to:

7.1 Describe situation/concerns with depleted uranium (DU) and potential disposition alternatives.

DEPLETED URANIUM

Definition, Sources, and Quantities

The NRC defines depleted uranium in 10 CFR 40.4 using three criteria. First, DU is source material containing 0.05% or more of uranium in any chemical or physical form. Second, DU does not contain special nuclear material, such as plutonium and uranium-233. Third, the uranium-235 assay of DU is less than 0.711% of the total uranium present (i.e., less than natural assay) and, thus, is depleted in uranium-235. Around enrichment facilities, this third criterion is usually the main one. DU assays typically span the 0.2–0.4% range, with 0.2-0.3% being the most common.

The overwhelming majority of DU accrues from enrichment operations. A very small quantity of DU has been produced from the reprocessing of nuclear fuel. DU is a byproduct of enrichment operations and its generation is unavoidable. As noted previously in this Self-Study Guide, the production of enriched uranium necessitates the creation of a depleted DU stream because of the mass balance. DU creation depends upon the desired LEU product assay, the enrichment process efficiency, the acceptable DU assay, and costs (e.g., of natural uranium and SWU). Current power reactors (LWRs) require 4.5–5% assay LEU in the fuel. If the enrichment process were 100% efficient, this would require a feed factor of about 7 and DU generation would correspond to about 6 times the product rate. In reality, enrichment processes are not 100% efficient and the feed factors approach 10, with DU generation around 9 times the product rate. Consequently, large quantities of DU exist both domestically and overseas (see Table 7-1), and these are stored.

Table 7-1. Approximate DU Worldwide

Company	Country	Approx. DU Inventory, te U		
		As UF6	As other	TOTAL
DOE and USEC	USA	490,000	10,000	500,000
(Various)	Russia/FSU	450,000	10,000	460,000
COGEMA/EURODIF	France	50,000	140,000	190,000
BNFL	UK	30,000	(-)	30,000
URENCO	Ger/Neth/UK	16,000	(-)	16,000
JNC/JNFL	Japan	10,000	(-)	10,000
CNNC	China	2,000	(-)	2,000
KAERI	Korea	200	(-)	200
(Various)	South Africa	4	69	73
TOTALS		1,048,204	160,069	1,208,273

Annual DU generation in the United States is approximately 9 times the LEU needs, tempered by any LEU quantities derived from HEU down-blending agreements. Annually, approximately 2,500 MTIHM/yr of LEU is needed, which would generate about 22,000 te of DU. HEU down-blending currently provides about 40% of current, domestic LEU requirements, and, consequently, DU generation is around 12,000–15,000 te/yr. More down-blending or imports of LEU will obviously decrease the domestic DU generation rate. Conversely, more domestic enrichment will increase DU generation; the proposed LES and USEC facilities will each generate approximately 8,000 te/yr of DU if constructed at their stated capacities (about 3 million SWU/yr per plant).

About 95% of the DU in the U.S. is stored as uranium hexafluoride, or DUF_6. The GDP process recovers DUF_6 in the liquid phase. The liquid DUF_6 drains into 48G (thin-walled cylinders) as part of enrichment operations. Once full, the cylinder is removed and allowed to cool, usually outside. After approximately five days, the liquid DUF_6 has cooled and solidified, and now occupies about 60% of the volume in the cylinder. Figure 7-1 shows solid UF_6 in a glass vial – note the irregularity of the crystal formation and the void spaces. Figure 7-2 displays a filled DU cylinder prior to movement. The GDPs store the DU cylinders outside in large yards. Figure 7-3 is an aerial shot of one of the large DU cylinder storage yards at the Paducah GDP. Figure 7-4 represents a closer look and Figure 7-5 depicts one of the aisles between cylinders used for inspections. The DU is stored at the three GDP sites in the following approximate proportions:

Paducah:	56% [of total] / 39,000 [cylinders]
Portsmouth:	28% / 16,000 (5,000 with Oak Ridge cylinders and others)
Oak Ridge:	16% / 5,900, being transferred to Portsmouth (by CY 2009)

Some of this DU has been stored for over 60 years.

Overseas, most DU is also stored as DUF_6 in cylinders. Figure 7-6 shows Uranium Byproduct Cylinders (UBCs) containing DU at one of the Urenco facilities. Note that the standard thickness, 48Y cylinders are used. Only France has a significant quantity of DU that is not stored as DUF_6; instead, it is stored as the oxide (U_3O_8) in metal containers, inside buildings.

Both LES and USEC plan to store DU outside in 48G cylinders, with two differences as compared to current GDP operations. First, the cylinders would be filled with DU via a desublimation process, where the DUF_6 vapor is directly condensed into the solid. This avoids liquid UF_6 and its associated ES&H concerns. Second, storage would be an interim step prior to shipment for deconversion and disposition.

Figure 7-1. Solid UF_6 in a Glass Vial, showing the irregularities

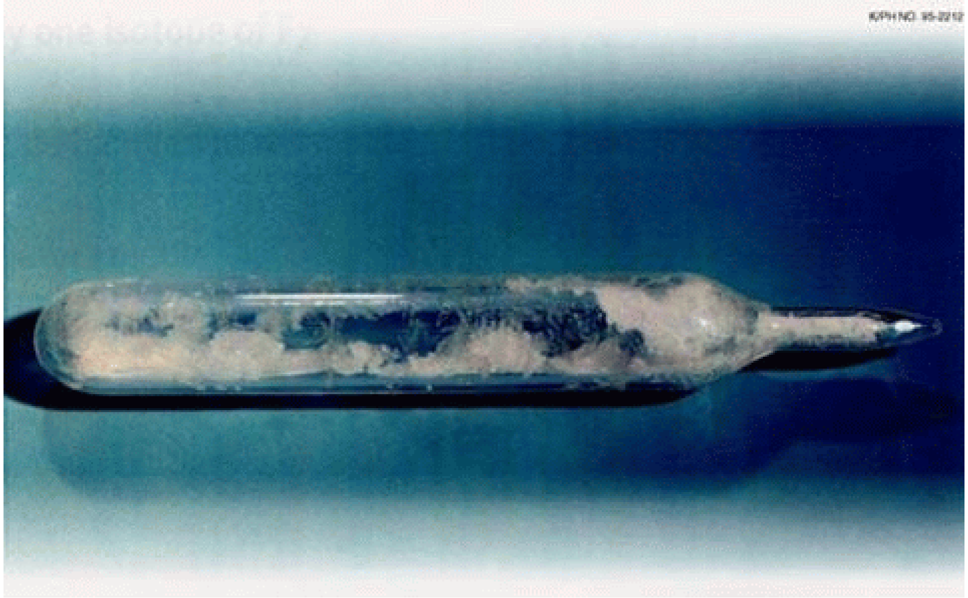


Figure 7-2. Filled DU 48G Cylinder

48G Depleted UF6 Storage Cylinder

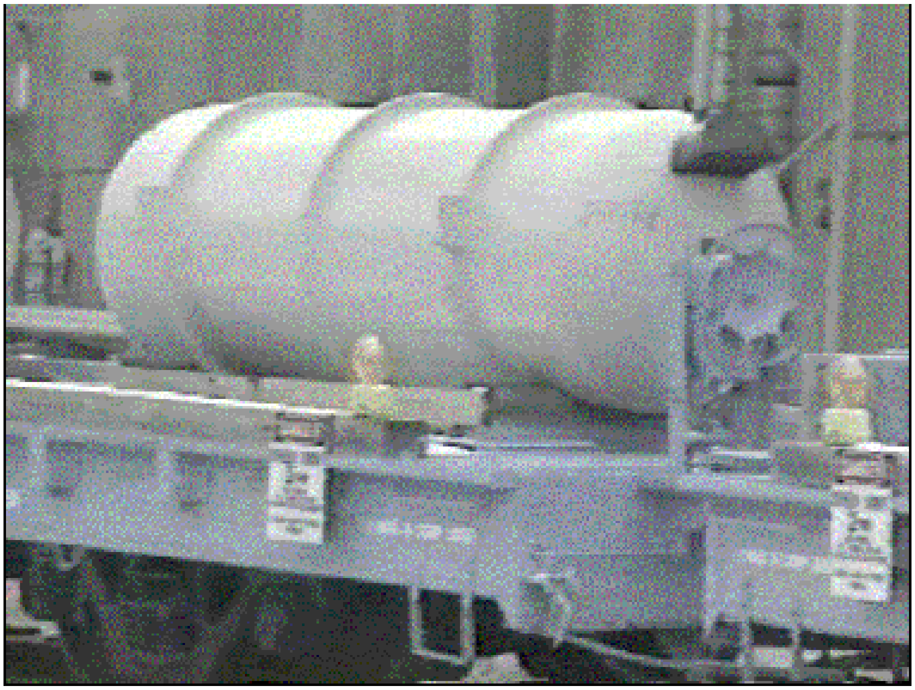


Figure 7-3. Depleted UF_6 Cylinder Storage Yard at a Gaseous Diffusion Plant Site

Figure 7-4. Close-up View Of DU Storage Yards (thin-wall 48G Cylinders)

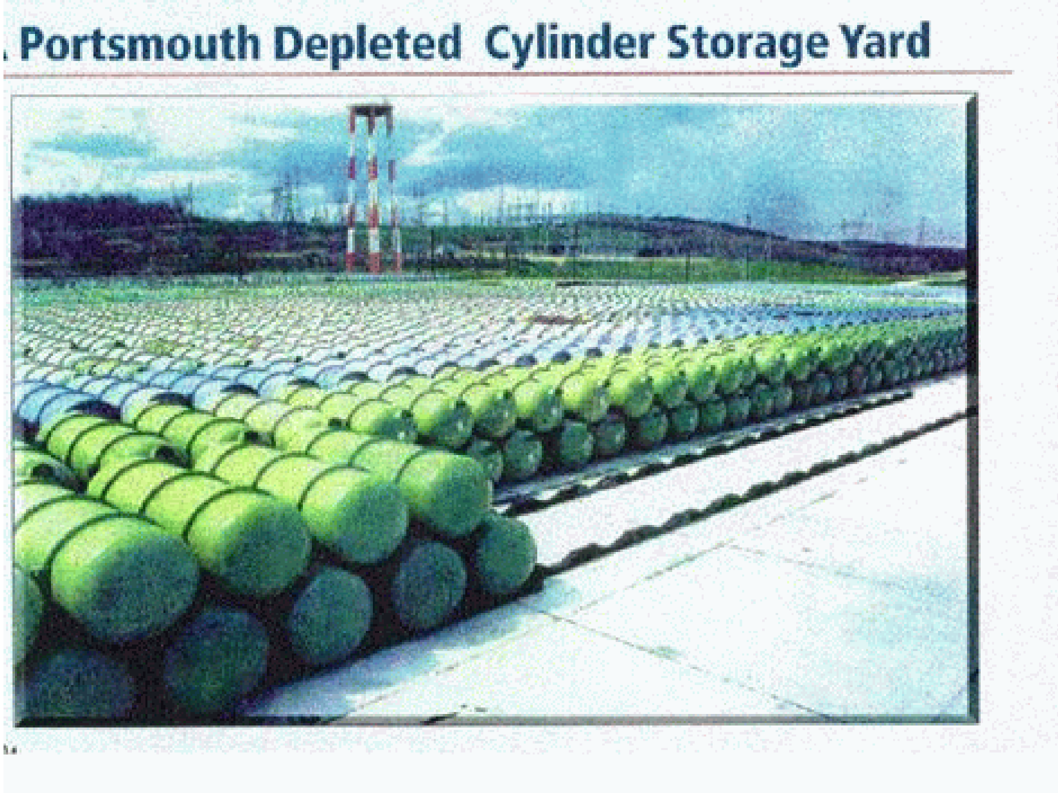


Figure 7-5. Inspection Aisle Between DU Cylinders

Storage of Depleted UF6 at Portsmouth

Figure 7-6. Urenco DU UBCs (Note: thick walled 48Y Cylinders, not 48G Cylinders as used at DOE and USEC facilities in the U.S.)

Learning Objective

When you finish this section, you will be able to:

7.2 Describe the environmental, safety, and health aspects associated with depleted uranium management.

ENVIRONMENTAL, SAFETY, AND HEALTH ASPECTS

DU storage, reuse, or disposition strategies, and the associated processing have to consider the environmental, safety, and health (ES&H) impacts involved. DU is a radioactive material. DU is also a heavy metal, and presents ingestion and inhalation concerns, depending upon the chemical form and pathways present. DU is more chemically toxic than radiotoxic; an acute (short term) DU inhalation or ingestion equivalent to about a 1 rem TEDE (i.e., a 50 year committed dose) which, radiologically, is a very small risk (circa 4E-4 risk of a long term cancer fatality from radiation), can correspond to a short-term fatality from the heavy metal (chemical toxicity) characteristics of DU (i.e., a risk of 1).

DU toxicity data primarily depends on the compounds and chemistry involved. Uranium and DU are considered to be potential carcinogens. Generally, soluble uranium compounds have short biological half-lives (weeks) and target excretory functions, such as the kidneys and the liver, leading to renal toxicity. Pulmonary edema can also result from DUF_6 exposure. Limits are based upon exposure concentrations and uranium uptake (essentially absorption into the body). Uptake is usually measured in milligrams; after a week or two, the soluble uranium has usually been excreted. Health effects are observable with uptakes of 10–30 mg, with fatalities starting above 30 mg; 200–300 mg uptake usually results in a significant mortality rate. In contrast, insoluble uranium compounds possess very long biological half lives (usually years) and target respiratory areas and bones. Inhalation constitutes the primary pathway. Chemical and radiation effects, including the short-lived DU daughter isotopes, produce the morbidity and mortality. From inhalation, pneumosclerosis (fibrotic scarring and thickening of tissues) and hyperplasia (abnormal cell growth and enlargement) occur within 1–2 years after exposure, generally followed by cancer within 4–5 years after exposure. Note that this is a relatively short timeframe for cancer development, and may be due to synergism between uranium's chemical toxicity and radiation effects. Tables 7-2 through 7-4 provide concentration limits for uranium compounds and the main chemicals that may be found in DU processing facilities.

The NRC is currently engaging stakeholders and the public on uranium uptake data and limits, and to see if any changes are needed.

Table 7-2. Uranium Hexafluoride AEGLs (Final)

[In mg/m^3]	**10 Minutes**	**30 Minutes**	**60 Minutes**	**4 Hours**	**8 Hours**
AEGL-1	3.6	3.6	3.6	NR	NR
AEGL-2	28	19	9.6	2.4	1.2
AEGL-3	216	72	36	9	4.5

NR=Not recommended due to insufficient data

Table 7-3. Hydrogen Fluoride AEGLs (Final)

[In ppm]	**10 Minutes**	**30 Minutes**	**60 Minutes**	**4 Hours**	**8 Hours**
AEGL-1	1	1	1	1	1
AEGL-2	95	34	24	12	12
AEGL-3	170	62	44	22	22

Table 7-4. TEELs/ERPGs (1 hour exposure) and IDLHs

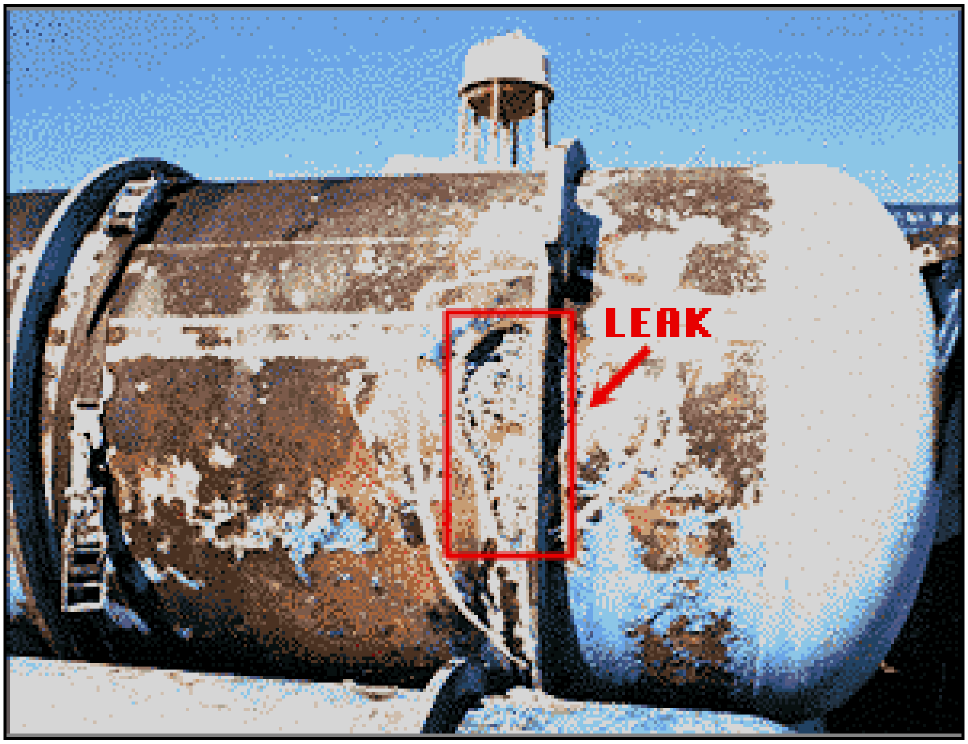
Compound [mg/m3 unless noted otherwise]	TEEL-0	TEEL-1	TEEL-2	TEEL-3	Comments	IDLH
Uranium – Soluble Compounds	0.05	0.6	2	10	TEEL	10
Uranyl Fluoride	0.0647	0.776	2.5	12.9	TEEL	(-)
Uranyl Nitrate	0.0828	0.993	0.993	16.6	TEEL	(-)
UNH	0.105	1.27	1.27	21.1	TEEL	(-)
Uranium – Insoluble Compounds	0.25	0.6	2	10	TEEL	10
Uranium Metal (mg/m3)	0.05	0.6	2	10	TEEL	(-)
Uranium Oxide (U_3O_8)	0.059	0.707	10	50	ERPG 2, 3	(-)

Table 7-4. TEELs/ERPGs (1 hour exposure) and IDLHs

Compound [mg/m3 unless noted otherwise]	TEEL-0	TEEL-1	TEEL-2	TEEL-3	Comments	IDLH
Uranium Dioxide (UO_2)	0.0567	0.681	10	30	ERPG 2, 3	(-)
Hydrogen Fluoride [ppm]	1	1	24	44	AEGL 1, 2, 3 Final	30 (as F)
Nitric Acid [ppm]	0.53	0.53	24	92	AEGL 1, 2, 3 Interim	25
Nitrogen Dioxide [ppm]	0.5	0.5	12	20	AEGL 1, 2, 3 Interim	20

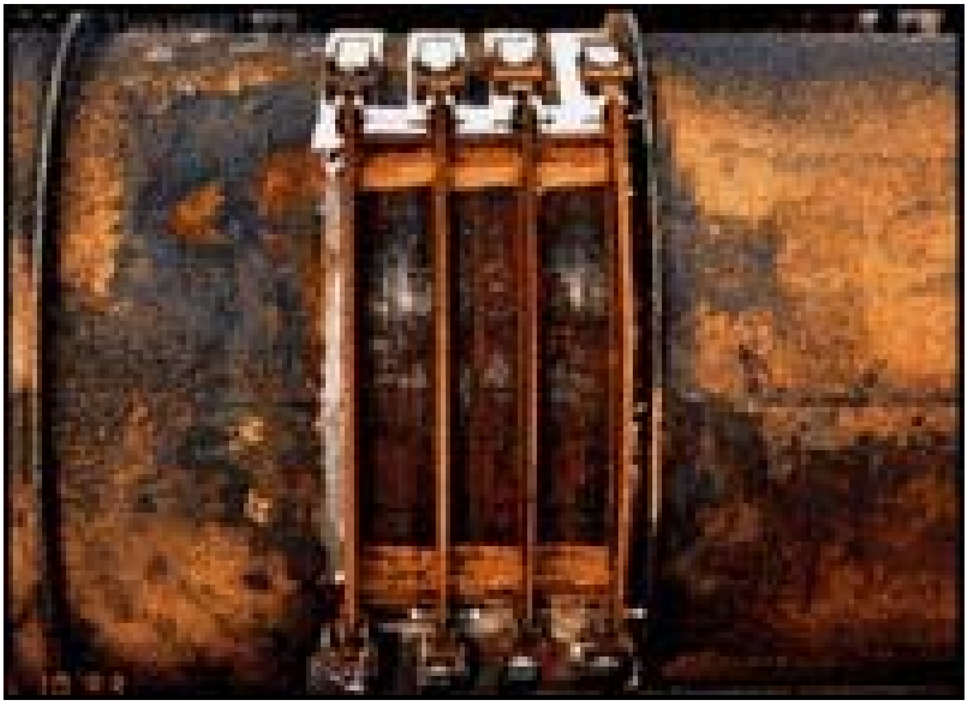
Most of the DU is stored as DUF_6, as a solid in outside cylinder yards. The potential exists for corrosion and reactions in storage, leading to contamination incidents and/or accidents. Both DUF_6 and the environment are corrosive to steel. Consequently, storage site operations routinely inspect the cylinders. Over some 60 years of storage, there have been a handful of breached cylinders caused by corrosion or misplacement of the cylinders. The solidified DUF_6 cylinders are at subatmospheric pressures (typically around 1 psia as compared to 14.7 psia for normal atmospheric pressure). Thus, a leak into the vapor space area has relatively little effect; the air rushes in, moisture slowly reacts with the solid DUF_6, and HF vapor slowly leaks out. A leak in the solid DUF_6 area has a similar effect but some DUF_6/DUO_2F_2 spillage can occur. Figure 7-7 shows a leak of solid DUF_6 from a cylinder. Small leaks like this are patched as in Figure 7-8 and the contaminated area cleaned. In general, the effects from a leaking cylinder containing solid DUF_6 are small and very localized. In contrast, any incident or accident that can damage a liquefied cylinder would have significant consequences due to the pressurized nature of the release (20 psia or more), typical liquid DUF_6 temperatures (circa 140°F), and the reactive nature of liquid DUF_6 upon a loss of confinement (i.e., the rapid formation of HF, explosive reactions with oils and organic materials). Liquid DUF_6 can be present from the initial filling operations (before it has cooled and solidified), processing of the DUF_6 (e.g., into other chemical forms), and from storage accidents involving fires, such as from the fuel tanks of cylinder transporters. Consequently, plant operations usually apply limits on the quantities of fuels and combustibles in and near DU cylinder storage areas.

Figure 7-7. DU Storage Cylinder with Leak



Cylinder Leak

Figure 7-8. Patched DU Storage Cylinder



Depleted UF6 Cylinder with a Patch

Typical radiation fields range between 1–20 mrem/hr around full DUF_6 cylinders. Radiation fields are circa one to two orders of magnitude greater with empty cylinders due to the presence of non-volatile daughter isotopes and the lack of self-shielding by the (now removed) DU.

Processing of DUF_6 into DU metal for reuse or storage has been proposed. DU metal has one of the highest densities of any compound (circa 19.2 g/cc) and, thus, mass effects and loadings must be considered. DU metal tarnishes in air, producing a non-protective oxide layer. DU metal slowly reacts with water to form hydrides, which can release hydrogen and exacerbate fires via difficult to predict mechanisms. The metal is pyrophoric as fine shavings, at room temperature. Bulk DU metal burns in air above temperatures of around 500°C. The melted metal is very reactive with air, moisture, and common materials of construction. Fires generate fine particles and have high release fractions. Therefore, inert atmospheres, special linings, special furnaces, and other precautions (e.g., keeping under oils or salt baths) are needed when machining and working with DU metal.

DU forms several oxides that may be present during processing, storage, reuse, or disposal of DU. These are insoluble uranium compounds. Oxides are usually generated as small, respirable particles, requiring confinement. Powder forms of the oxides have low densities, typically 1.5–3 g/cc. Sintered (i.e., heat treated to remove pores), aggregated forms may have densities of 6–11 g/cc. U_3O_8 (the octaoxide) possesses the greatest thermodynamic stability at room temperature. UO_3 also has reasonable stability at room temperature and is thermodynamically the most stable at temperatures several hundred degrees above ambient. UO_2 is thermodynamically the least stable of the oxides but can be kinetically stable. As a fine, respirable powder, say, 10 microns or less in diameter, UO_2 undergoes an exothermic reaction called burnback and converts to UO_3 or U_3O_8. This reaction has started fires and damaged HEPA filters in past events at fuel fabrication facilities. If the UO_2 is aggregated to a larger size and sintered, it forms a very stable medium at room temperature (N.B. this is the basis for using UO_2 as nuclear fuel). Under certain conditions of heat and steam (generally above 120°C), sintered UO_2 can react in air, releasing heat and increasing its volume, and potentially shattering any container it is in.

No source provides toxicity data for uranium carbides (e.g., uranium monocarbide and uranium sesquicarbide). Coated or uncoated uranium carbides represent insoluble uranium compounds and fall into that category for toxicity evaluations. Carbides are usually prepared from the oxides via high temperature processes. Normal methods produce dense microspheres around a millimeter or so in diameter, with densities of 10–13 g/cc. Carbides are metastable in normal air; they slowly react with air and moisture, converting back to uranium oxides. This process results in swelling and cracking of the microspheres due to the lower densities of the oxides. Coated carbides incorporate carbon and silicon carbide coatings around the uranium carbide microspheres. These coatings are very resilient and essentially render the uranium carbide microsphere inert to its environment.

DU processing may involve uranyl fluoride and nitrates. These have the toxicity concerns of soluble uranium compounds. As stored chemicals, they would only be present in relatively small quantities and are non-volatile, and, thus, pose relatively small hazards. In contrast, DU processing uses and can release chemicals, such as hydrogen fluoride, nitric acid, and nitrogen oxides, in sufficient quantities and concentrations that can produce significant hazards miles downwind from the facilities. These require safety controls.

Learning Objective

When you finish this section, you will be able to:

7.3 Describe DU disposition pathways including, storage, reuse, and disposal.

DISPOSITION ALTERNATIVES

Domestically and as noted previously, some 500,000 MTU exists, primarily as DUF_6 at the GDP sites. Ongoing operations at the Paducah GDP produce 10,000–14,000 MTU annually. The NRC has issued licenses and construction commenced on two gas centrifuge enrichment facilities that would each generate approximately 8,000 MTU of DUF_6 annually, for 30 years, based upon current plans. Two other companies have announced plans to develop additional enrichment capacity in the U.S. which would produce even more DU. These represent significant DU quantities and all will require disposition.

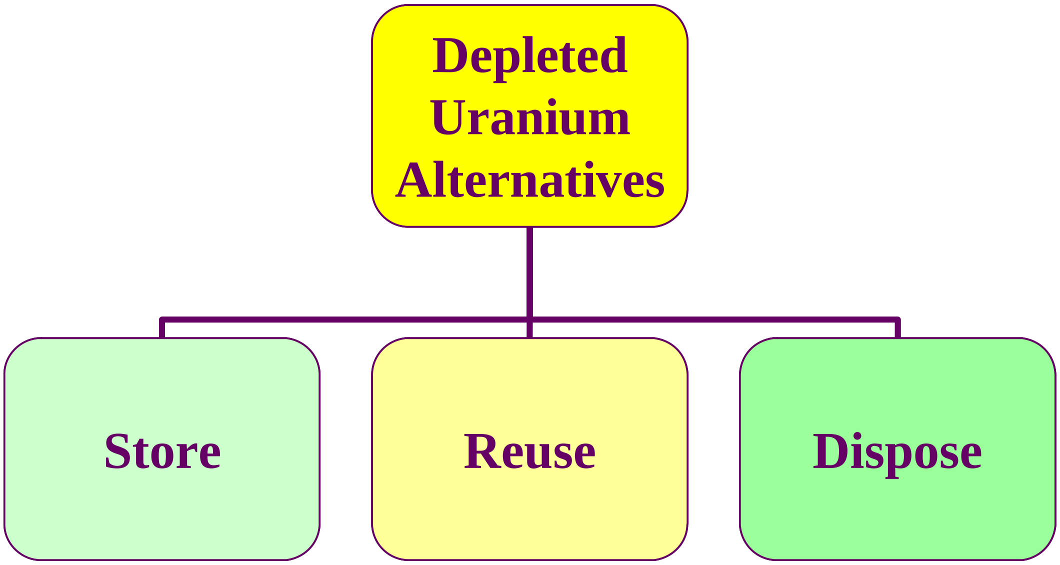
Disposition requires large facilities and costs. Estimates range from one to ten billion dollars just for processing the DU material itself. Some high benefit applications require the use of multi-billion dollar facilities (e.g., reactors and reprocessing/recycling facilities).

Figure 7-9 portrays the three disposition alternative pathways for DU; it can be stored, reused, or dispositioned, essentially like a waste. Key considerations for each alternative are:

- Major or partial consumption of DU
- Chemical and physical forms
- Processing methods and facilities
- Containers, confinement, or other means to control contamination
- Locations for processing, storage, disposal, or reuse
- Decommissioning and closure requirements

These are briefly discussed for each pathway.

Figure 7-9. DU Disposition Pathways



Storage

Current storage as the solid DUF_6 has a container density of around 3 g/cc. Storage as the DU oxide powder would have a similar container density. Sintered uranium dioxide forms would have container densities of 6-9 g/cc. Storage as the metal would likely involve ingots or derbies, with container densities approaching 19 g/cc.

<u>Major or partial consumption of DU</u>: Some, all, or none of the DU can be stored. DU is currently quantitatively stored as the hexafluoride at most enrichment facilities worldwide. All U.S. DUF_6 is stored in DUF_6 cylinders (48G type).

<u>Chemical and physical forms</u>: DU is currently stored as the hexafluoride. It can be stored in several different forms. The most suitable chemical forms are uranium octaoxide, uranium trioxide, uranium dioxide, coated uranium carbides, and, to a lesser extent, uranium metal, due to thermodynamic or kinetic stability, and high densities. The fluorides (hexafluoride and tetrafluoride) are less suitable for long-term storage due to corrosion, reaction, and accident considerations. Bulk physical forms, such as briquettes or pellets, in steel containers, are more suitable.

<u>Processing methods and facilities</u>: Storage in any other form than DUF_6 requires processes applied on a large scale (probably greater than 10,000 MTU/yr) and large facilities. Processing technologies and facilities should address the ES&H concerns of liquid DUF_6, preferably by avoiding its creation.

Containers, confinement, or other means to control contamination: Facility designs have to address confinement of DU and its daughter isotopes during processing and storage. Facility confinement requirements are more extensive if liquid DUF_6 is involved in the processing facilities. Steel storage containers stored inside are more suitable.

Locations for processing and storage: Location of processing facilities at or nearby existing storage locations offers many advantages including minimal transportation needs. Colocation of the new storage facilities would be beneficial, even though the DU form should be easier and safer to transport.

Decommissioning and closure requirements: DU storage can be either a short-term or a long-term interim measure. Decommissioning/closure approaches, technologies, requirements, and funding should be considered as part of the storage decision.

Reuse

Current reuse scenarios are discussed in more detail. Many reuse applications rely upon the density of the DU form, with higher densities being preferred.

Major or partial consumption of DU: Some, all, or none of the DU can be reused. Several reuse scenarios clearly have the potential capability to utilize all of the DU (e.g., fast reactor use, shielding for SNF disposal containers) or require treatment of all of the DU (e.g., re-enrichment), while others clearly do not (e.g., semiconductors).

Chemical and physical forms: The majority of the reuse applications require the DU in a dense, oxide form. Metallic or coated carbide forms may also be usable for shielding and reactor applications. Macroscopic physical forms (e.g., pellets, briquettes) with isolation/coatings are more suitable. Re-enrichment may or may not use DUF_6.

Processing methods and facilities: Reuse in any other form than DUF_6 requires processes applied on a large scale (probably greater than 10,000 MTU/yr) and large facilities. Processing technologies and facilities should address the ES&H concerns of liquid DUF_6, preferably by avoiding its creation.

Containers, confinement, or other means to control contamination: Facility designs have to address confinement of DU and its daughter isotopes during processing. Facility confinement requirements are more extensive if liquid DUF_6 is involved in the processing facilities. A preferable DU form for reuse incorporates encapsulation, confinement, or other means to address contamination and other ES&H concerns.

Locations for processing and reuse: Location of processing facilities at or nearby existing storage locations offers many advantages including minimal transportation needs. Reuse would likely require transportation to another location (and may require additional processing at another location) and may or may not incorporate institutional controls for handling radioactive materials.

Decommissioning and closure requirements: DU reuse can be either a short-term or a long-term measure. Decommissioning/closure approaches, technologies, requirements, and funding should be considered as part of the reuse decision. Some DU reuse applications inherently address these issues (e.g., DU shielding for SNF disposal canisters), while other applications may follow a general license – “lightbulb” – approach with general landfill disposal.

Disposal

Major or partial consumption of DU: Some, all, or none of the DU can be sent to disposal.

Chemical and physical forms: The majority of the disposal approaches requires the DU in a dense, oxide form. Metallic or coated carbide forms may also be usable but would require more testing and qualification. Macroscopic physical forms (e.g., pellets, briquettes) with isolation/coatings are more suitable.

Processing methods and facilities: Disposal requires conversion of the DUF_6 into the desired form on a large scale (probably greater than 10,000 MTU/yr) and using large facilities. Processing technologies and facilities should address the ES&H concerns of liquid DUF_6, preferably by avoiding its creation. Disposal may utilize multiple facilities and disposal units/cells; dedicated facilities may also be used.

Containers, confinement, or other means to control contamination: Facility designs have to address confinement of DU and its daughter isotopes during processing. Facility confinement requirements are more extensive if liquid DUF_6 is involved in the processing facilities. A preferable DU form for disposal incorporates multiple barriers, such as the DU chemical form, DU physical form, coatings, binders, encapsulants, containers, disposal site location, disposal site construction, or other means to address contamination and other ES&H concerns.

Locations for disposal: Location of processing facilities at or nearby existing storage locations offers many advantages including minimal transportation needs. Disposal would likely require transportation to another location (and may require additional processing at another location) and will incorporate institutional controls for handling radioactive materials. Arid disposal locations with reducing soil and groundwater chemistries may be more suitable. NRC analyses on DU disposition indicated that near-surface, shallow land disposal at an Eastern U.S. site would result in ingestion doses far above the 25 mrem/yr limit. The NRC concluded disposal in a site deeper than normal shallow land disposal practice (e.g., a mine cavity) would experience reducing leaching chemistry that would not exceed the 25 mrem/yr limit. However, subsurface disposal, such as in a mine, does not currently exist. The NRC did not evaluate an arid site for DU disposal. However, near-surface disposal at arid sites may meet dose limits; performance assessments will need to be completed if such sites are selected for DU disposal.

Decommissioning and closure requirements: DU disposal is a long-term measure. Retrievability will likely be limited once the disposal cell or site closes. Site specific licenses will be required. Decommissioning/closure approaches, technologies, requirements, and funding for the processing facilities should be considered as part of the disposal decision.

Learning Objective

When you finish this section, you will be able to:

7.4 Describe reuse alternatives for DU that require regulation by the NRC.

REUSE ALTERNATIVES

Many reuse alternatives involve commercial applications, and, thus, require regulation by the NRC. Currently, SNF shielding in storage or disposal canisters/casks, using dense UO2, may be the most plausible reuse option, as the oxide is stable (for either storage or disposal applications), the approach provides clear benefits, regulations are relatively well defined, a market exists and could consume the majority of the DU, economics appear reasonable, there is some precedence, and ES&H concerns are reduced vis-à-vis other DU materials (e.g., DU metal/alloys).

Reuse alternatives that could only partially use the DU inventory and quantities for **nuclear** purposes, applications include the following:

(1) Re-enrichment. Re-enrichment would use advanced, highly efficient and cost-effective enrichment technologies to remove the residual uranium content of DU from around the 0.2–0.4% range to 0.05% or lower, and produce an LEU product of circa 5% assay suitable for LWR use. Laser enrichment (AVLIS and MLIS) has been mentioned due to its high selectivity. Using 0.3% as the starting assay of the DU, 5% for the product assay, and 0.05% as the new DU assay, the DU inventory would be reduced about 5%. For 500,000 MTU, this would be a 25,000 MTU reduction, or about 1,000 MTU/yr, assuming a 25 year schedule. A large enrichment facility (multi-million SWU/yr) would be needed.

Urenco shipped some of its DU to Russia for re-enrichment to around natural assay levels. The natural assay material was returned to Urenco as new feed for enrichment. The (now further) depleted stream remained in Russia. This program occurred due to a surplus of enrichment capacity on the market; the surplus has since disappeared and the program has been canceled.

Currently, there are no plans to re-enrich DU domestically.

(2) MOX Fuel. MOX fuel uses 6–7% total plutonium (about 5% fissile plutonium) in a uranium dioxide matrix. Usually the uranium is DU. Currently, only about 500 metric tons of initial heavy metal (MTIHM)/yr of MOX fuel are used worldwide and none is used domestically. If all of the plutonium in U.S. LWR SNF annual discharges was recovered and recycled once, it would accrue to a little over 500 MTIHM/yr as MOX, of which approximately 500

MTIHM/yr would be DU. Large reprocessing plants (circa 2,500 MTIHM/yr) and large MOX fuel fabrication facilities would be required. For perspective, this equates to the entire current commercial reprocessing/recycling capacity currently operating in Europe and Japan.

MOX represents a small usage of DU and is practiced in several countries overseas.

Reuse Alternatives that could only partially use the DU inventory and quantities for **non-nuclear** applications include the following:

(1) Catalysis. DU possesses catalytic properties because of the many available electron orbitals, particularly the 6d and 5f shells. Experimental tests have shown DU can be an effective catalyst for reactions such as:

- Oxidation of volatile organic compounds (VOCs) and chlorinated VOCs
- Selective oxidation and ammoxidation
- Partial oxidation of methane to methanol
- Oxidative coupling (hydrocarbon chain lengthening)
- Selective Catalytic Reduction (SCR) of NO

Catalytic applications use DU as the oxide on a substrate such as silica, alumina, or metal oxides (e.g., molybdenum, antimony). There were limited, commercial test applications of uranium catalysts in the 1960s and 1970s. No significant usage of DU as a catalyst occurs currently, and, if they did occur, catalyst applications would only result in small DU consumption.

(2) Semiconductor Applications (computer chips, solar cells, thermoelectric/thermoionic applications). Uranium Oxides have electrical and electronic properties equivalent to or much better than the properties of conventional Si, Ge, and GaAs semiconductor materials, and, thus, offer the potential for a new, higher performance class of semiconductors. The energy band gap for uranium dioxide lies between silicon and gallium/arsenide, at the optimum of the band gap-efficiency curve, indicating uranium dioxide could be used to make very efficient photovoltaic cells, semiconductors, or other electronic devices. The electrical conductivity of uranium dioxide approximates that of gallium/arsenide, but the dielectric constant is almost double that of gallium/arsenide or silicon, potentially making DUO2 a better choice for integrated circuits. Uranium oxides also have characteristics that could give them significantly better performance than conventional conductor materials: operation at substantially higher temperatures and greater radiation and EMF

resistance implying they may be better suited for use in hazardous environments (e.g., space).

Junctions between uranium dioxide and another thermoelectric material or metal form a thermoelectric cell, similar to a thermocouple. Thus, a temperature gradient across the material produces an electric current (this is the basis for the radioactive thermal generators used in spacecraft) or, alternatively, an electrical gradient applied across the materials offers a refrigeration effect. Potential combinations indicate solid-state refrigerators or heat pumps could be made that are more efficient than current, vapor-compression cycles.

Experiments have confirmed some of the electronic properties of uranium dioxide. Properties strongly depend upon the stoichiometry of the material. The effects of dopants on the semiconductor properties of uranium have never been measured. Actual devices have not been manufactured and tested to verify performance. The potential impact of radioactive decay is expected to be small due to the long half-lives of the materials; however, this requires confirmation by measurements and testing.

Small applications of DU as a semiconductor are possible, but DU consumption would be small. DU, if used in semi-conductors, in the unlikely event that DU is used in semiconductors at a level equivalent to the current usage of silicon, the consumption would approximate the annual production rate of depleted uranium from uranium enrichment facilities.

(3) <u>Counterweights</u>. DU materials possess high densities. DU metal has a density of about 19 g/cc — much higher than lead (circa 10.2 g/cc). Sintered uranium dioxide has a density around 10 g/cc. Uranium carbides have densities between 11–13 g/cc. Consequently, these materials (usually the metal) have been used as counterweights. Many commercial aircraft use DU metal counterweights. Total consumption is small.

Reuse Alternatives That Could Substantially Or Totally Use The DU Inventory And Quantities for **nuclear** applications include the following:

(1) <u>Shielding</u>. DU is a high atomic weight element, and, as such, functions very effectively as a shielding material for gamma radiation. Metallic DU performs better than lead, resulting in reduced thicknesses and weights for the same shielded dose. Metallic DU has only found limited application in shielded containers to date.

Spent Nuclear Fuel (SNF) is extremely radioactive, and SNF handling and storage require heavy shielding. SNF emits both

> gamma and neutron radiation; therefore, effective shielding must reduce both to acceptable levels. Historically, container designs apply a heterogeneous shielding approach. Heavy materials like lead and steel (and DU metal) attenuate gamma radiation. A separate, outer shield incorporates light elements such as boron impregnated plastic for neutron attenuation. DU compounds offer the possibility of homogeneous gamma and neutron shielding materials for SNF containers and casks. Potential DU compounds include nuclear fuel compounds like DUO2 and DU carbides (DUC and DUC2), DU silicates, and cermet combinations. Matrix materials, such as concrete, plastics, and carbon pressed forms, hold the DU together and provide additional radiation attenuation.

Figure 7-10 displays calculated shielding properties for DU metal, Ducrete (a DUO2/concrete mixture), and Pyruc (DUO2 or DUC in a carbon matrix), utilizing a 24 PWR SNF assembly source term. For comparison, a standard concrete cask would require a 30-36 inch thickness for comparable dose rate reductions. Thus, the use of DU forms offers the potential for reducing the shielding thickness by 50–70%, with a corresponding reduction in weight. DU forms, particularly Pyruc combinations, may allow sufficient heat transfer by conduction that labyrinthine air cooling passages would not be needed. The shielding consumes approximately 40 MTHM of DU and the total weight is reduced to around 70 te, as compared to a little over 100 te for the current steel container incorporating lead for shielding, for comparable external radiation fields. Figure 7-11 shows a shielded container incorporating Ducrete. Figure 7-12 represents a top view of an SNF canister, without the shielding. Figure 7-13 provides a design from the literature for a DU shielded, SNF canister.

A standard SNF storage canister holds approximately 12 MTIHM of SNF. Although not yet designed, a disposal canister is likely to hold a slightly less but similar quantity of SNF. Thus, if DU is used as shielding in these canisters, the current SNF inventory could consume some 200,000 te of DU, and the total projected SNF inventory from existing reactors through their current planned operating lifetimes might use circa 500,000 te of DU.

DU has also been proposed as a backfill or internal shielding material for the SNF containers. DUF_6 would be converted to an oxide form, perhaps as a sand-like material, and poured into the canister, conceivably after vacuum drying the canister. Subsequently, the gas spaces would be backfilled with helium. The DU backfill increases heat transfer as well as providing some shielding benefits. Multiple tonnes of DU could be used per cast. Similar DU forms have been proposed as a backfill material around an SNF disposal canister in the repository.

DU for shielding or backfill in SNF storage and disposal containers has the ability to consume the majority of the DU.

Currently, there are no significant applications of DU for shielding purposes and none is planned.

Figure 7-10. Shielding Behavior of DU Forms

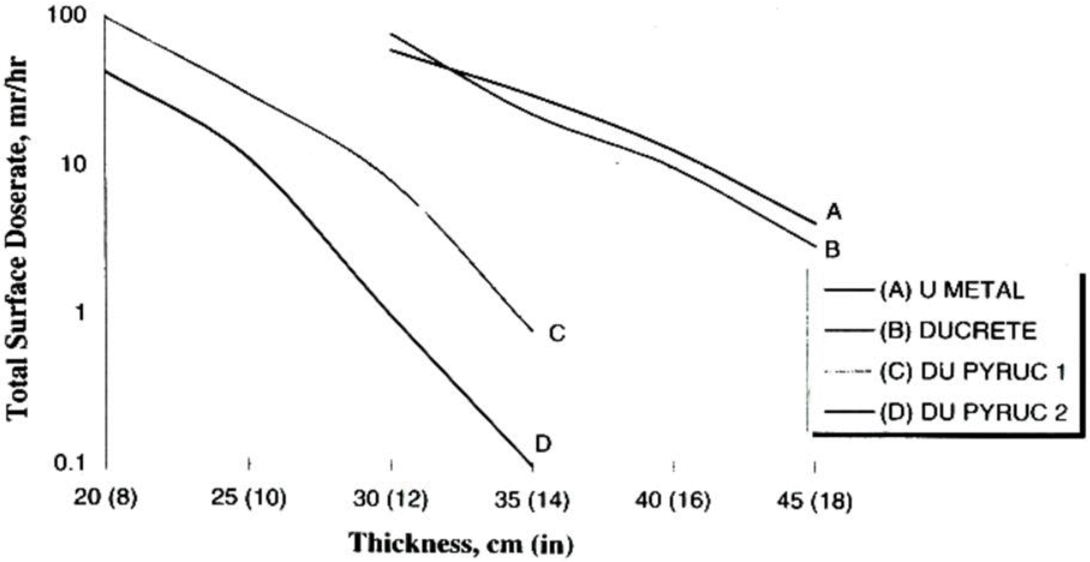


Figure 7-11. Ducrete Shielded Storage Container for a Standard Drum (The Ducrete is sandwiched between stainless steel surfaces)

Figure 7-12. Top View of a Typical SNF Storage Container or Canister for Assemblies, (without the concrete shielding)

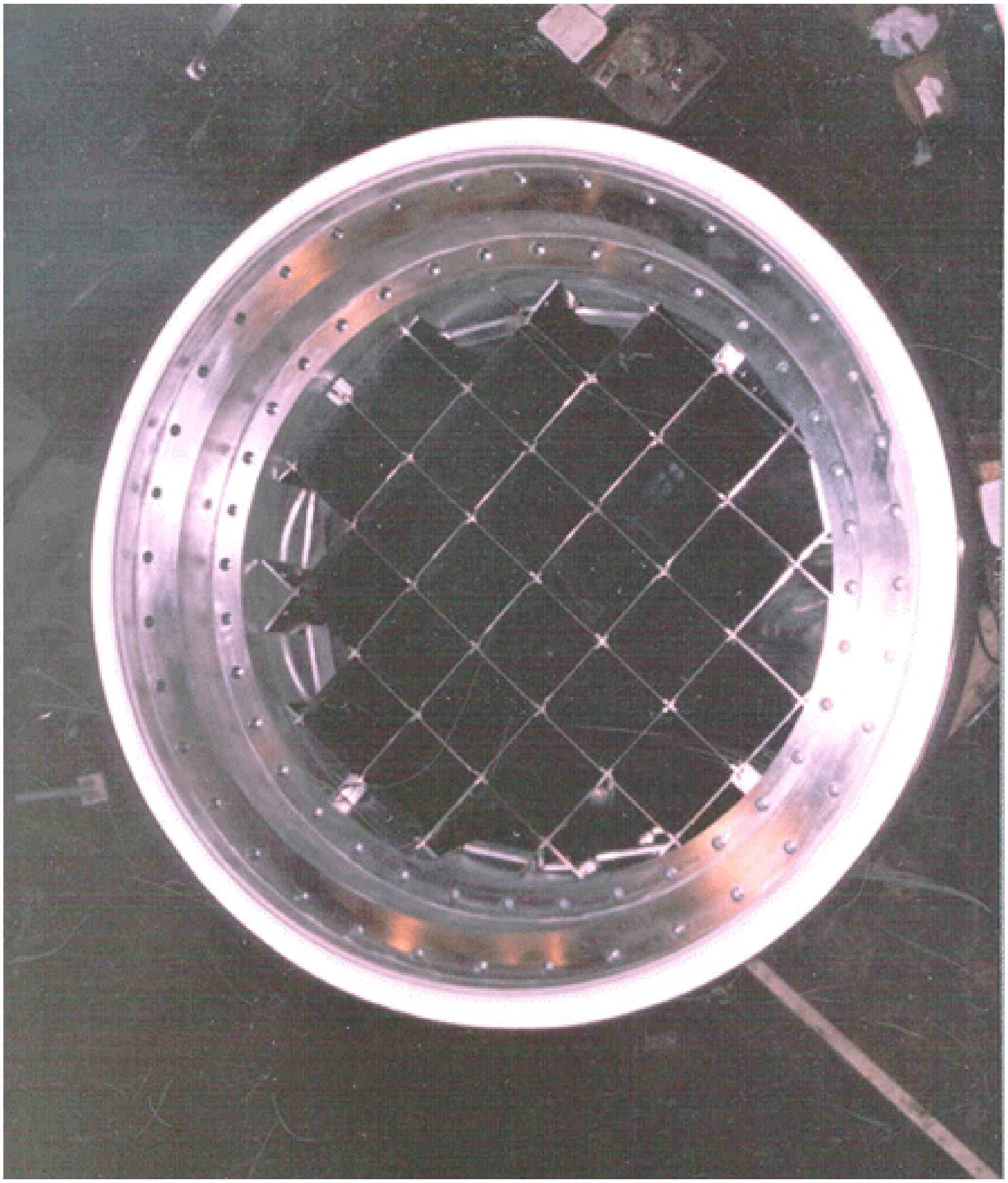
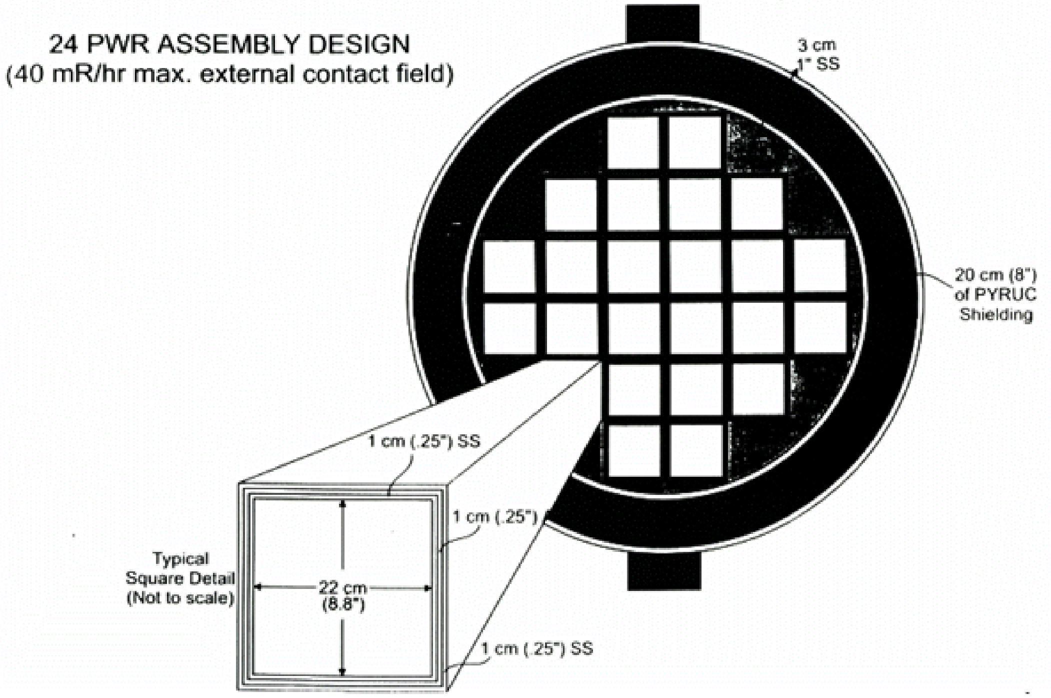


Figure 7-13. Literature Cask Design Incorporating DU Shielding



Fast Reactor/Breeder Reactor

Uranium represents energy. Current LWRs utilize about 1% of the total energy available in natural uranium. Plutonium recycle in MOX increases this to about 1.5–2%. Fermi realized in the late 1940s that a fast neutron spectrum would convert uranium-238 into plutonium-239 (Figure 7-14) at a faster rate than the plutonium would be consumed due to the additional neutrons released by the fission reactions. This forms the basis for the breeder reactor and was one of the original, underlying reasons for storing the DU from enrichment. The use of DU in a fast breeder reactor raises the energy utilization to 70–80% or more of the total available in uranium.

Sodium cooled fast breeder reactors have been discussed as the most likely approach for utilizing DU. The following assumptions allow an estimate to be made of the energy content of the DU:

- current inventory of DU: 500,000 te(U)
- 200 MEV per fission
- 90% of fission energy released as heat
- 40% conversion ratio of thermal energy into electricity

- 100% recovery of the energy in the DU
- Total U.S. Energy is about 100 Quads/yr (1 quad = 1E15 BTU) (2005 data)
- Total U.S. Electricity = 3,660 billion KW-hr/yr = 1.3176E19 Joules/yr = 12.5 Quads/yr electrical output (not thermal input) = 418 GWe (average; all 2005 data)

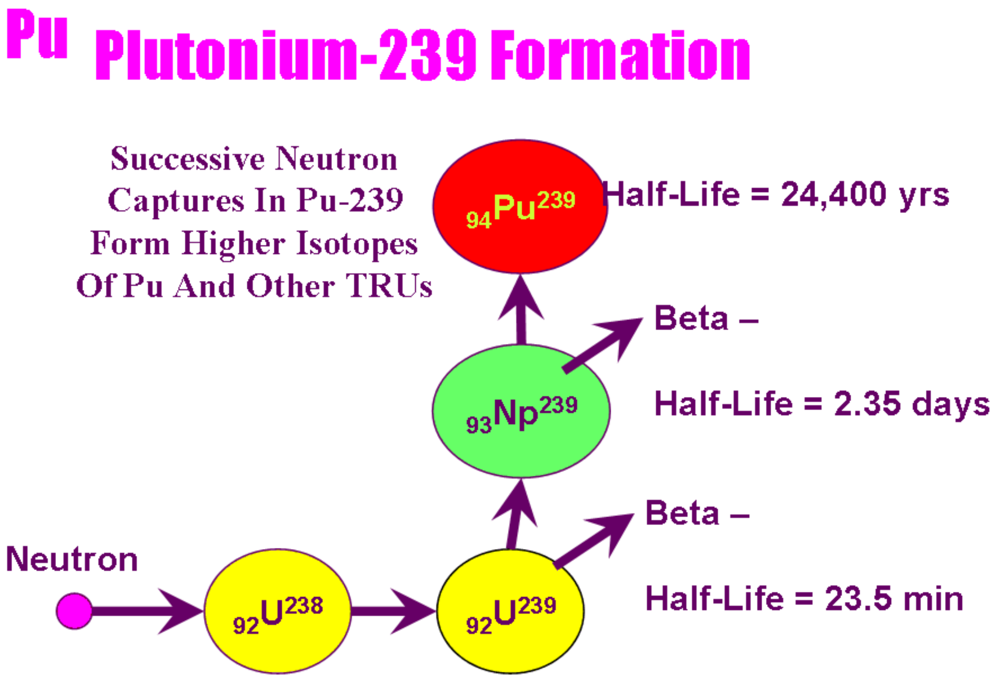
The calculations indicate the existing, U.S. inventory of DU, if converted into nuclear fuel and utilized in fast breeder reactors, is equal to at least 1,100 years of the current, entire electrical consumption of the U.S. Thus, significant DU consumption could be attained.

At the present time, the U.S. is not pursuing fast breeder reactors. Overseas, several countries are pursuing fast breeder reactors because of this significant energy content of DU.

The Global Nuclear Energy Partnership (GNEP) is a DOE program established in 2006 to expand the use of nuclear power and address several issues, including SNF management and disposal. GNEP plans to reprocess the LWR SNF, perhaps recycle some of the plutonium back to LWRs as MOX fuel, and to subsequently utilize fast spectrum reactors to consume (“burn”) the transuranic isotopes and generate electricity; these reactors are termed ABRs for Advanced Burner Reactors. The program is in its embryonic phase with few specific details, but the majority of the fuel matrices would consist of DU. The program requires long timeframes but it could result in a substantial consumption of DU.

Currently, there are no non-nuclear applications that could consume the majority of the DU inventory and annual generation rates.

Figure 7-14. Formation of Plutonium-239 by DU Fast Neutron Absorption and Successive Beta-Decays



Learning Objective

When you finish this section, you will be able to:

7.5 Describe the role DOE plays in depleted uranium management.

DOE AND DU

DOE possesses the title to the majority of DU in the U.S. and is required by law to accept DU from commercial enrichment facilities for a fee equivalent to the cost of dispositioning the material. DOE conducted numerous studies and NEPA activities regarding DU, issued three environmental impact statements, and developed a program to address DU disposition. The program follows three paths:

- Path 1: Surveillance and maintenance of current cylinder storage.
- Path 2: Technology development, primarily for reuse applications.
- Path 3: Large scale deconversion of DUF_6 into uranium oxide (essentially U_3O_8).

Under Path1, DOE and its contractors improve the yards by grading, improving drainage, extra storage pads, proper cradles for the cylinders, rearrangement of cylinders to allow easier inspections, cleaning and painting of the cylinders with corrosion resistant paint, and patching of leaking cylinders. After some fifty years, very few cylinders (perhaps 10 out of 60,000) have leaked and required patching.

There is uncertainty regarding future leakage rates – i.e., will the rate increase as the cylinders age and corrode?

Under Path 2, DOE and its contractors are developing technologies for reusing DU. These have been discussed in the previous section.

Under Path 3, DOE has decided upon large scale deconversion of DUF_6 into uranium oxide U_30_8, followed by short term, temporary storage of the oxide. If reuse applications do not develop, DOE would send the DU oxide to disposal, either at the Nevada Test Site or a commercial facility. In 2003, DOE selected Uranium Disposition Services LLC (UDS) to design, construct, and operate a deconversion facility at the Paducah and Portsmouth sites.

Figure 7-15 depicts the process. The approach involves dry deconversion of UF_6 into uranium oxide, as practiced by several nuclear fuel fabrication facilities. Autoclaves heat and liquefy the DUF_6 cylinders, forming a vapor stream to feed the process.

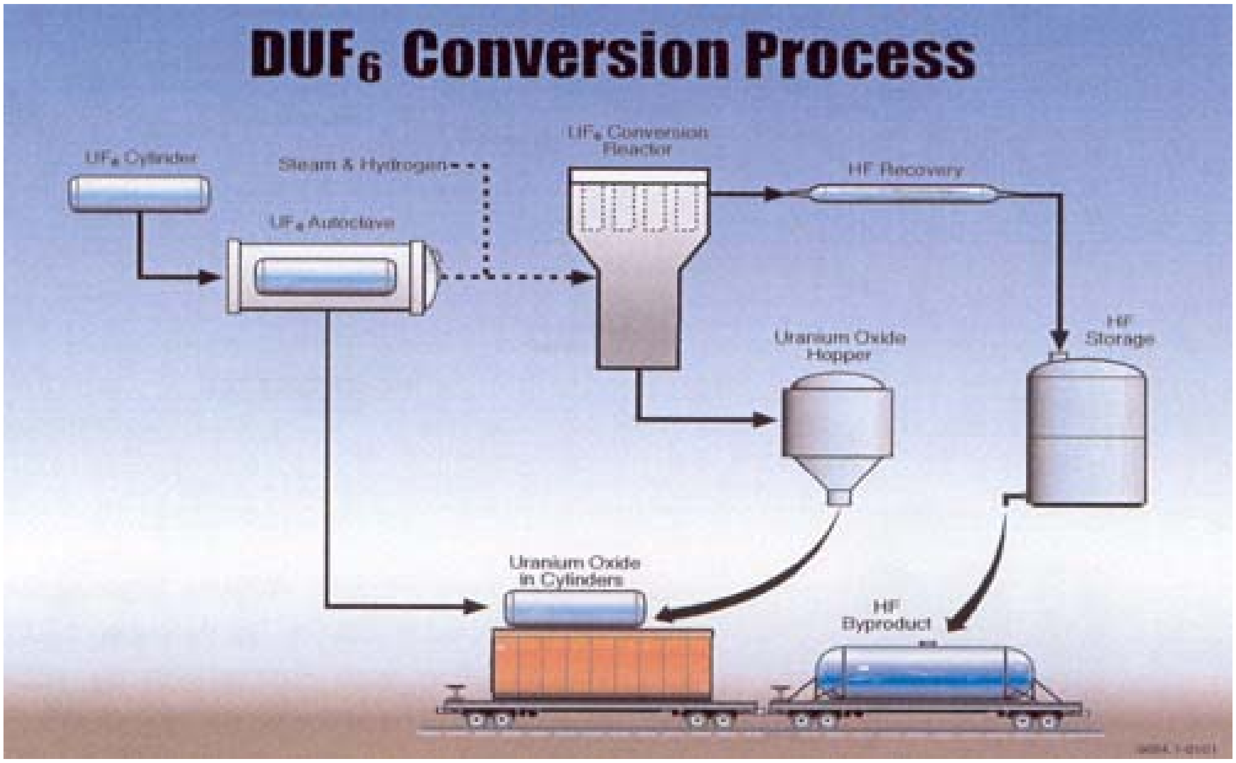
The DUF_6 reacts with steam and hydrogen under controlled conditions, according to the reactions:

$$UF_6 + 2\,H_2O = UO_2F_2 + 4\,HF \qquad \text{(exothermic)}$$

$$UO_2F_2 + H_2 + H_2O = UO_x + HF \qquad \text{(endothermic)}$$

The reactions form uranium oxide powder and aqueous hydrogen fluoride (HF). The plan is to sell the HF back to commercial industry for unrestricted reuse provided the uranium content is negligible. The emptied cylinders may be reused for the uranium oxide or compacted and sent to disposal as low-level waste. The process also includes scrubbers, filters, and monitoring equipment for process control and environmental protection.

Figure 7-15. Diagram of Deconversion Process



DOE is the lead regulator of the two deconversion facilities. However, recycle and reuse of the aqueous HF in commercial applications would require approval by the NRC or an Agreement state. The NRC has previously approved recycle and reuse of aqueous HF or calcium fluoride from licensed fuel fabrication facilities based upon process analyses, analytical results (e.g., residual uranium content), and a pathway analysis demonstrating compliance with 10 CFR 20 free release limits for the public (usually less than 25 mrem/yr). The uranium oxide powder will likely be a low density material. Additional processing would be necessary for reuse of the uranium oxide powders, most of these reuse applications would be regulated by the NRC.

Construction commenced in 2005. Figure 7-16 shows the Paducah facility, which contains four lines and has a design capacity of 18,000 te/yr (about 1,500 cylinders/yr). Figure 7-17 shows the Portsmouth plant, which contains three lines and has a design capacity of 13,500 te/yr (about 1,125 cylinders/yr).

Figure 7-16. Deconversion Facility Under Construction at Paducah

Figure 7-17. Deconversion Facility Under Construction at Portsmouth

Learning Objective

When you finish this section, you will be able to:

7.6 Describe the approach to depleted uranium management used outside the United States.

OVERSEAS APPROACH TO DUF$_6$ MANAGEMENT

Most enrichment operations overseas store the DUF$_6$ indefinitely. Urenco and AREVA/Eurodif are the two exceptions.

The European Urenco facilities at Almelo, Capenhurst, and Gronau store the DUF$_6$ in 48Y thick-walled cylinders. Urenco maintains an account for conversion and disposal of the DU (as U_3O_8), predicated upon a $10/kg U estimate. Urenco intends to build and operate its own deconversion facility or contract out for the service in the near future.

Areva/Eurodif operates the GDP at Tricastin, France, in the Rhone Valley. GDP operations are being phased out and replaced with GC enrichment of similar SWU capacity. The plant has operated for over twenty years and, consequently, a DUF$_6$ inventory exists and continues to accumulate. Typical DU assays range from 0.2 to 0.3%.

French nuclear regulators require Areva/Eurodif to include DUF$_6$ conversion and storage costs as part of the fee charged for the enrichment services. The regulators also require conversion of the DUF$_6$ into the more stable form, DU oxide (U_3O_8). Areva considers DU to be valuable as a future resource, perhaps as a feedstock for fast breeder reactors, and not a waste material. Consequently, Areva operates a DUF$_6$ conversion facility at Pierrelatte, France. This plant processes the DUF$_6$ into an oxide powder using a dry process, in a manner very similar to the DOE deconversion facilities. Aqueous HF is sold for unrestricted, commercial recycle. The oxide powder product has a low density, and the plant compacts it to a density of 3–4 g/cc. The plant places the compacted DU oxide into steel containers. The containers are transported by rail to the site of the former uranium mill Besines-sur-Gartempe near Limoges for long term storage. Potentially, the facility could store up to 200,000 te DU. Storage of the DU oxide has survived several legal challenges because it is an interim measure prior to future DU use of fast reactors.

Learning Objective

When you finish this section, you will be able to:

7.7 Discuss the NRC’s involvement in depleted uranium management in the future.

NRC INVOLVEMENT AND THE FUTURE

The NRC has analyzed the generation of DU at enrichment facilities numerous times over the past twenty years and concluded only limited quantities would be reused. Thus, the majority would have to be dispositioned as waste. Also, any significant reuse applications would most likely be regulated by the NRC.

Claiborne Enrichment Center

The license application was received by the NRC in 1991. DU became a significant issue for the staff and citizen’s groups. The staff conducted numerous analyses related to DU and completed its review of the license application. The Safety Evaluation Report was issued in January 1994 as NUREG-1491; the Final Environmental Impact Statement was issued in August 1994 as NUREG-1484. The LES-1 plant would have generated about 3,830 tonnes of DU annually. LES initially planned to store the DU indefinitely, following DOE practices at the time. However, the NRC concluded there were few uses for the DU and that most of it would have to be dispositioned as if it were low level waste. NRC analyses found DU to be a Class A low-level waste, and that near-surface disposal at a generic site in the Eastern U.S. would result in ingestion doses significantly above regulatory limits (Part 61; essentially a 25 mrem/yr dose limit) because of the oxidizing nature of surface waters solubilizing the DU_3O_8. However, the NRC analyses showed that deeper disposal, such as in a generic mine, would reduce doses below regulatory limits because the water chemistry became reducing and did not readily solubilize the uranium.

After multiple interactions with the NRC, LES modified its plan to have the DUF_6 deconverted into DU_3O_8 at an offsite facility, followed by disposal in a mine cavity or deeper type of disposal unit. (Such a mine disposal unit for LLW did not exist at the time and does not exist today.) DU_3O_8 would be stored onsite until the deconversion and disposal facilities and arrangements were completed; DU shipment offsite was to commence within 15 years of the generation of DU and payments would be continuously made into a sinking fund to address financing concerns. DU disposition accounted for approximately 90% of the estimated decommissioning cost of the proposed facility. The facility was not constructed and the DU management provisions were not implemented.

DOE DU Disposition Program

In 1995, DOE conducted a public process as part of its DUF_6 management program. The NRC provided a response based upon its analyses for the CEC/LES-1 facility; namely, there were few uses for DU, most of it would have to be dispositioned as waste, and that, for disposal, it would be a Class A low level waste.

NRC Comments on DOE DU PEIS and "Roadmap"

The NRC subsequently provided comments on the DU PEIS and a DU disposition roadmap document from DOE. Again, the NRC concluded there were few uses for the quantities of DU available, most of it would have to be dispositioned as waste, and, for disposal, it would be a Class A low level waste. The NRC also noted there were benefits from making a dense form, such as sintered uranium dioxide, as such dense forms occupy less volume, leach more slowly, and are more compatible with potential reuse scenarios.

Commission Determination

In January 2005, the NRC ruled on DU:

- DU is a LLW. The Commission used the 10 CFR 61.2 definition for LLW in its considerations. The Commission noted LLW is generally acceptable for near surface disposal and that disposal as LLW is a plausible strategy.
- DU is subject to the 1996 USEC Privatization Act. Section 3113 requires DOE to accept for disposition DU from any NRC licensed enrichment facility for a fee covering the costs of such disposition.
- The FY 2005 Energy Policy Act requires DOE to take title and possession to such DU at an existing DU storage or processing facility.

The Commission rulings constitute acknowledgement of a plausible path forward. Licensing and inspection activities on enrichment applications would provide specific details. For example, the suitability of a specific disposal site, the suitability of near-surface disposal, the suitability of specific DU chemical/waste forms, the site's ability to accept DU quantities and concentrations, and the ability to meet disposal dose requirements were not considered at the time of the ruling but would be considered during the NRC licensing of new enrichment facilities, DU processing facilities, and disposal sites accepting DU. In addition, the proposed use of non-NRC licensed facilities (e.g., DOE facilities) would be evaluated by the NRC for its suitability if such a route were proposed as part of an enrichment application. In summary, the NRC concluded DU disposition was plausible and reasonable, and an enrichment facility would not be allowed to operate without addressing DU disposition in a timely manner.

LES-2 and USEC

LES-2 (National Enrichment Facility-NEF, Hobbs, N.M.) plans to store depleted uranium tails on-site on the Uranium Byproduct Cylinder (UBC) pad until they are transferred to another licensee for commercial use or they are designated for disposal as waste. If designated as waste, the LES-2 is proposing to use either a commercial disposition path or the U.S. Department of Energy (DOE) disposition path set out in the USEC Privatization Act of 1996. As part of an agreement with the State of New Mexico, LES-2 has committed to not store any depleted uranium cylinder for longer than fifteen years, not store more than 5,016 DU cylinders onsite at any time, and increase the contingency to 50% if more than 4,000 cylinders are in storage at any one time.

LES-2 identified the waste processing and disposal cost of UF_6 tails as $4.68 per kilogram of uranium (kg U) or $4,680 per metric ton of uranium (MTU). This cost is based on the total of the three cost components that make up the total disposition cost for DUF_6 (i.e., deconversion, disposal, and transportation). LES-2 will establish a contingency fund to cover the costs of DU disposition using either DOE or commercial facilities. LES-2 has signed agreements with commercial firms regarding the potential construction of a deconversion facility nearby and disposal at a site in Texas.

USEC will store depleted UF_6 tails in steel cylinders, within cylinder storage yards, until the cylinders are transferred to DOE or another facility for deconversion; until decommissioning; or until they are transferred to another licensee for commercial reuse. At or before the time of decommissioning, any remaining UF_6 tails will be converted to a stable oxide form and disposed of in accordance with the USEC Privatization Act. USEC has indicated a preference for using DOE as the disposition pathway for DU tails, but has kept the option open for deconversion and disposal using other licensed facilities.

At USEC's request, DOE provided a cost estimate for dispositioning depleted uranium generated by the applicant. USEC estimated the waste processing and disposal cost of UF_6 tails at $4.62 per kilogram of uranium (kg U). This cost is based on the total of the three cost components that make up the total disposition cost for DUF_6 (i.e., deconversion, disposal, and transportation).

As explained in their respective FSERs, the NRC concluded these approaches (set up a DU fund, use DOE or commercial disposition pathways, and limits on the DU site inventory) provided reasonable assurance DU disposition will occur in an appropriate and timely manner.

The NRC is continuing its review of DU management and disposition, and considering the need for specifically including DU in Part 61 limits.

Self-Check Questions 7-1 ✓

1. What is depleted uranium (DU)?

2. Is DU a source material?

3. Identify the approximate amount of DU in the U.S.

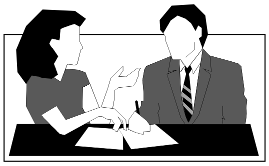
4. Is DU predominantly a radiation or a chemical toxicity hazard?

5. Name several potential reuse scenarios for DU.

6. Identify the three program paths developed by DOE to address DU dispositon.

7. At the Arerva/Eurodif GDP in Tricastin, France, GDP operations are being phased out and replaced with what technology?

8. Identify three NRC rulings in DU from January 2005?



Progress Review Meeting Form

Date Scheduled:________________________________**Location:**______________________

I. The following suggested items should be discussed with the administrator as to how they pertain to your current position:

- Describe situation/concerns with depleted uranium (DU) and potential disposition alternatives.
- Describe the environmental, safety, and health (ES&H) aspects associated with depleted uranium management.
- Describe DU disposition pathways including storage, reuse, and disposal.
- Discuss reuse scenarios in more detail. Many reuse applications rely upon the density of the DU form, with higher densities being preferred.
- Describe the role DOE plays in depleted uranium management.
- Describe the approach to depleted uranium management used outside the United States.
- Discuss the NRC’s involvement in depleted uranium management in the future.

II. Use the space below to take notes during your meeting.

III. As a Regulator:

- What have been the most recent issues with Depleted Uranium?
- Tell me more about NRC regulation of depleted uranium.

Use the space below to write your specific questions.

IV. Further assignments? If yes, please note and complete. If no, initial completion of progress meeting on tracking form.

Ensure that you and your administrator have dated and initialed your progress on your tracking form for this module. Go to the module summary.

MODULE SUMMARY

DU is generated by all enrichment processes in large quantities, and large inventories exist at the GDP sites domestically and at enrichment sites overseas. The DU generation rate is anticipated to increase as enrichment services more domestic reactors. The principal chemical form of DU is as the hexafluoride, in steel cylinders stored outside, and this presents environmental, safety, and health concerns due to the DUF_6 reactivity and toxicity from potential cylinder failures and accidents. DU can continue to be stored, reused, or dispositioned as waste. Potential large reuse scenarios include spent nuclear fuel shielding containers and energy generation in fast breeder reactors. Other reuse scenarios, such as re-enrichment and MOX fuel, or non-nuclear applications, such as catalysts and semiconductors, would only consume modest quantities of DU. Currently, no significant reuse applications exist or are planned. Waste disposal would require conversion of the DUF_6 into an oxide, such as DU_3O_8 or UO2. DOE is building facilities to convert the DUF_6 into DU_3O_8, for temporary storage, followed by disposal if no reuse applications arise. The NRC requires DU disposition to be addressed as part of any application for an enrichment facility. Overseas, France converts DUF_6 into DU_3O_8 for long-term storage and future use in its breeder reactor program as an energy source.

Key Points

- Some 700,000 tonnes of DU are stored domestically, almost entirely as DUF_6 at the Paducah and Portsmouth sites.

- The DU generation rate exceeds 10,000 tonnes annually and is likely to increase.

- There are ES&H concerns associated with DUF_6 storage, particularly from cylinder failures and accidents involving fires.

- DU use as shielding in spent nuclear fuel containers and in breeder reactors represent large reuse applications.

- Re-enrichment, MOX fuel, and semiconductor applications represent smallscale reuse applications.

- DOE is constructing large plants to convert DUF_6 to DU_3O_8, for interim storage and, if no reuse applications arise, disposal. Potential accidents at these facilities could affect NRC-licensed activities nearby.

NRC has concluded limited reuse scenarios exist and most DU would require dispostion as low level waste. Waste disposal requires the DUF_6 to be converted to DU oxide.

Congratulations!

You have completed the final module of the Uranium Enrichment Directed Self-Study Course. Go to the Directed Self-Study Course Process in the Trainee Guide. Ensure completion of all process steps.