MANUFACTURING SCIENCES CORPORATION

USERS GUIDE TO MSC MATERIALS

DEPLETED URANIUM

NATURE AND SOURCE

Depleted Uranium (DU) is a by-product of the uranium enrichment process whereby the fissionable isotope ^{235}U is extracted from natural uranium. After separation of ^{235}U, the energy source material for reactors, the DU that remains is used in making military and commercial products.

Uranium occurs in nature as an oxide and is mined as U_3O_8, which contains about 0.7 wt% of the fissionable isotope ^{235}U. The impure U_3O_8 is converted to UO_3. UO_3 is then hydrofluorinated to form UF_6, a gas, at slightly elevated temperature and reduced pressure. UF_6 is processed through a gaseous diffusion plant or gas centrifuge plant to separate the isotopes in the form of $^{235}UF_6$ and $^{238}UF_6$. The US Department of Energy enriches natural uranium from 0.7 wt% ^{235}U to 3 -5 wt% ^{235}U for commercial reactor fuel. For each kilogram of uranium that is enriched to 3 wt% ^{235}U, five to six kilograms of DU containing about 0.2 wt% ^{235}U are produced.

Historically, the enrichment process has produced more DU than is being used. Consequently, the Department of Energy has produced a large stockpile of material, estimated at 300,000 to 500,000 metric tons, in the form of uranium hexafluoride (UF_6). This waste by-product of the enrichment process becomes the basic raw material in the production of DU metal, which is readily available and inexpensive.

REDUCTION

Uranium hexafluoride (UF_6) is chemically reduced with hydrogen to produce uranium tetrafluoride (UF_4), commonly referred to as "green salt". Green salt is reduced to metal by an exothermic reaction with magnesium. The product of the reaction is a high purity, uranium metal mass, referred to as a "derby".

CASTING

Derbies and recycle materials are melted in vacuum induction, melting furnaces at MSC. Each furnace has a uranium melt capacity of 4,500 kilograms. Uranium is cast (alloyed if desired) into finished products or cast into ingots for further processing. MSC employs both top and bottom pouring techniques in combination with three-zone heating in the mold chamber to control solidification. The furnace is designed to bottom load the crucible and molds to maintain environmental cleanliness.

ROLLING

Ingot castings are preheated in a molten carbonate salt bath to 650° C prior to rolling. Rolling occurs on a four-high, reversing mill equipped with hydraulic screwdowns to produce sheet. The mill has 9-meter long, powered run-out tables with guides for centering the plate. One set of run-out tables has a powered, split-roll feature to facilitate cross rolling if desired. The mill width is 1 meter with a typical maximum opening of 165 millimeters. The back-up rolls are 1 meter in diameter, and the work rolls have a useful diameter between 470 and 420 millimeters. The pass schedule is controlled by computer through a servo-hydraulic, optical encoder loop that enables accurate reproduction of rolling schedules.

Rolled sheet may be rough sheared, sawed, reheated and rolled directly to final gauge. A 17-roll, 1.5 meter wide roller leveler may be used to achieve the desired flatness. The rolling schedule and subsequent heat treatment are dependent upon the texture, grain size and mechanical properties desired.

HEAT TREATMENT

MSC has a variety of vacuum, heat treating furnaces. The largest is capable of a 2700-kilogram load inside a three zone, 3.6-meter long, 1.2-meter wide hot zone. The maximum temperature is 1000° C with a vacuum level typically below 5 x 10^{-2} torr. The computer controls allow for a wide range of thermovacuum cycles that take advantage of the inert, gas quenching system integral to the furnace.

FABRICATION

Depleted uranium plate and sheet are precision sheared, punched and/or machined to final dimension on computer, numerically controlled machines. Fabrications are inspected with digital gages, templates and/or coordinate measuring machines. Typical tolerances are shown in the table below.

Sheet flatness	+/- 0.25 mm per 1000 cm^2
Shearing	+/- 0.25 mm
Punching	+/- 0.18-mm true position
Lathe turning and Milling	+/- 0.05 mm

Formed parts can be pressed to net or near-net shape under a 100-tonne or 300-tonne hydraulic press.

ASSEMBLY

Uranium products may be coated or clad to protect the surfaces and reduce exposure to personnel involved with subsequent handling in the field or to comply with regulatory requirements. Various coating materials such as acrylic paint, zinc, and nickel may be applied.

PROPERTIES

Crystal Structure:	Orthorhombic (alpha)
	Complex Tetragonal (beta)
	Body-Centered Cubic (gamma)
Atomic Weight:	92
Density:	19.0 g/cc (pure)
Melting Point:	1130C

Representative Properties of DU Sheet*

	Pure	U3/4%Ti	U2%Nb	U6%Nb
Ultimate ksi (Mpa):	110 (758)	225 (1551)	212 (1462)	120 (827)
Yield ksi (Mpa):	60 (414)	140 (965)	150 (1034)	25 (172)
Elongation (%):	20	18	18	32
Reduction in Area (%):	30	30	42	38
Hardness (Rc):	21	45	47	10
Toughness ksi• $in^{1/2}$ (MPa• $m^{1/2)}$:	28 (31)	34 (37.4)	44 (48.4)	43 (47)
Density lb/in^3 (gm/cm^3):	0.68 (19.0)	0.67 (18.6)	0.64 (17.8)	0.62 (17.3)
Elastic Mod. ksix1000 (Gpa):	20 (138)	--	20 (138)	--

Note: Properties depend strongly on processing history and can be tailored to meet specific requirements.

Mechanical Behavior: See Reference 4, available upon request.

Mass Attenuation and Energy-Absorption Coefficients: See References 5 and 6, excerpts attached.

Thermal Expansion: See References 7, 9, and 10, excerpts of Reference 7 attached. Others available upon request.

Coatings (Zinc): See Reference 11, available upon request.

Material Safety Data: See Material Safety Data Sheet.

Radioactive Materials License: Available upon request.

APPLICATIONS

Depleted uranium is used in applications where its combination of high density, fabricability, relatively good mechanical properties and availability give it an advantage over other materials. There are several commercial and military non-nuclear uses of depleted uranium:

COMMERCIAL: Calorimeters/Detectors, Radiation Shielding, Counterweights, Flywheels, and Sinker Bars

MILITARY: Kinetic Energy Penetrators, Shape Charge Liners and Explosively Formed Penetrator Lenses, Armor

Calorimeters/Detectors: DU sheet is in wide-scale use as an absorber material in high-energy physics research at large accelerator laboratories. The high atomic number and density of DU presents a large number of atoms per unit volume to interact with the particles emerging from collisions in these detectors. Also the slight background radiation from DU enables insitu calibration of the electronic read out devices within such detectors, thereby improving the accuracy of measurement.

Radiation Shielding: Containers made of DU are used to transport highly radioactive, spent fuel elements and radioactive isotopes for medical and industrial applications. In addition, DU is used as shields in medical equipment for radiation therapy.

Counterweights: Counterweights made of DU are used in aerodynamic, control devices of airplanes, missiles and helicopters.

Miscellaneous: Flywheels have been made of DU for large, inertial, energy-storage devices and as sinker bars for oil well logging.

Kinetic Energy Penetrators: Kinetic energy penetrators are made of DU because of its high density, fabricability, pyrophoricity, availability and low cost compared to other heavy metals.

Shape Charge Liners and Explosively Formed Penetrators Lenses: Depleted uranium SCLs and EFP lenses are under investigation as a material for warhead applications in missiles, ammunition and submunitions.

Armor: The U.S. Army has revealed that depleted uranium is used as armor protection in the Abrams main battle tank.

LICENSING AND REGISTRATION:

Ownership, production and use of DU are subject to state and federal regulations. Title 10, Part 40, of the Code of Federal Regulations describes the requirements for obtaining a Radioactive Materials License. Manufacturing Sciences Corporation is licensed by the State of Tennessee under authority as an Agreement State as granted by the U.S. NRC. Our license number is S-01046-L00. MSC is licensed to manufacture, store, transport and dispose of DU. MSC can assist users in obtaining general licenses if one is required.

In general, possession of more than 15 lbs. of uranium requires a license from the U.S. NRC or authorized Agreement State. However, users are exempt from this requirement for the following applications:

1. Uranium contained in counterweights installed in aircraft, rockets, projectiles or missiles, or stored or handled in connection with installation or removal of such counterweights when:

    a. The counterweights are manufactured in accordance with the specifications contained in a specific license or equivalent licensing document issued by the NRC or Agreement State;

    b. Each counterweight has been impressed with the following legend legible through any plating or other covering: "DEPLETED URANIUM";

c. Each counterweight is durably and legibly labeled or marked with the identification of manufacturer and the statement "UNAUTHORIZED ALTERATIONS PROHIBITED"; and
d. The exemption contained in this subparagraph shall not be deemed to authorize the chemical, physical, or metallurgical treatment or processing of any such counterweights other than repair or restoration of any plating or other covering.

2. Uranium used as shielding constituting part of any shipping container which is conspicuously and legibly impressed with the legend "CAUTION - RADIOACTIVE SHIELDING - URANIUM" and which is encased in mild steel or equally fire resistant metal of minimum wall thickness of 1/8 inch.
3. Uranium contained in detector heads for use in fire detection units, provided that each detector head contains no more than 0.005 microcuries of uranium.

In addition, other local, state, and federal regulations may apply and should be checked prior to possession or use of uranium.

HEALTH EFFECTS

There are three properties of the metal which require special precautions during fabrication and use:

- Radioactivity
- Toxicity
- Pyrophoricity

Radiation: Depleted uranium is a low specific activity (LSA) material. The radiation from DU is primarily non-penetrating; that is, it is very easy to shield so that it has little or no effect on people who handle it. In fact, DU is used as shielding for radioactive material.

Depleted uranium emits three types of radiation - alpha, beta, and gamma. While alpha radiation is insignificant as an external radiation hazard (skin stops alpha particles), it becomes a problem if inhaled or ingested. Once in the body, alpha rays, because of their short range and high ionization, are potentially more hazardous than beta or gamma radiation.

The permissible limits for radiation exposure are designated in Title 10, Part 20, Code of Federal Regulations. The limits are equivalent to an average of 100 mRem of exposure to whole body radiation per week and 625 mRem to the hands or feet. Operating experience using film badges and ring dosimeters indicate that persons working with DU receive very low levels of exposure to radiation compared to the permissible limits.

The greatest problem working with DU comes from finely divided airborne particles that can result from some manufacturing operations such as machining and grinding. It is essential to provide machine ventilation, area ventilation and special filtering equipment to protect workers from radioactive dust and particles that could be inhaled or ingested into the body where radiation may affect body organs. Machines are enclosed and ventilated, and air monitoring and frequent urinalysis are conducted to ensure controls are effective.

Toxicity: Depleted uranium, like lead, is a heavy metal poison that can be lethal if a sufficient amount of dust or fumes are ingested. The fact that DU is radioactive is helpful in this regard because it is much easier to detect its presence and protect against ingestion than it is for other non-radioactive, heavy metals like lead, tungsten or tantalum.

Pyrophoricity: A pyrophoric metal is one that oxidizes rapidly, that is, can "burn" in air. DU becomes pyrophoric only when finely divided. Because pyrophoric reactions take place at the surface of the metal, surface condition and the amount of exposed surface area are critical. Solid metal oxidizes slowly. A smoothly machined surface slowly turns to a tea color, and within a few days turns black.

Machine turnings, particularly fine turnings having literally hundreds of square meters of surface area per kilogram, may react sufficiently to generate enough heat to cause ignition if they are not kept cool under water. Grinding sludge with still larger surface area may react even under copious quantities of water.

Finely divided scrap is kept inert by storing it under water or mineral oil. Scrap prepared for shipment to disposal sites may be mixed with an inert insulation material such as sand or concrete to ensure that no reaction occurs during transport.

Fires are extinguished by cooling the uranium and by restricting access of oxygen to the uranium by covering it with graphite powder or with a dry powdered chemical extinguisher. Water should never be used on uranium fires. Water reacts with the hot metal and generates hydrogen, which exacerbates combustion.

REFERENCES

1. "Standards for the Protection Against Radiation," Code of Federal Regulations, 10CFR20.
2. Radiological Health Handbook, U.S. Department HEW, U.S. Government Printing Office, January 1970.
3. P. Loewenstein, "Industrial Uses of Depleted Uranium," Metals Handbook - Properties and Selection, Volume 3, Ninth Edition, American Society for Metals, pp. 773-780.
4. K. H. Eckelmeyer and F. J., Zanner, The Effect of Aging on the Mechanical Behaviors of U-.75wt%Ti and U-2wt%Mo, November 1975.
5. J. H. Hubbell, Photon Mass Attenuation and Energy-absorption Coefficients from 1KeV to 20 MeV, Center for Radiation Research, National Bureau of Standards, Washington, D.C., July 1981
6. Photon Cross Sections, Attenuation Coefficients and Energy Absorption Coefficients from 10KeV to 100 GeV, U.S. Department of Commerce, National Bureau of Standards, NSRDS-NDS 29.
7. Y. S. Touloukain, R. K. Kirby, R. E. Taylor, and P. D. Desai, Thermophysical Properties of Matter, Volume 12, IFI/Plenum, New York-Washington.
8. L. T. Lloyd and C. S. Barrett, "Thermal Expansion of Alpha Uranium," Journal of Nuclear Materials 18 (1966), North-Holland Publishing Co. Amsterdam, May 1965.
9. M. W. Poore and K. F. Kesterson, "Thermal-Expansion Measurements on Uranium 0.8% Titanium Alloy," Report No. Y/DL-629, Union Carbide - Oak Ridge Y-12 Plant, May 3, 1979.
10. R. W. Logan and D. H. Wood, "Thermal Expansion of Rolled and Extruded Uranium," Journal of the Less-Common Metals, 90 (1983) 233-241, Materials Science Division, LLNL, July 20, 1982.

11. J. L. Briggs, "The Corrosion Resistance of Zinc Coatings on Depleted Uranium and Uranium Alloys," Rockwell International RFP-3651, UC-25 Materials, DOE/TIC-4500, Rev. 73, January 27, 1985