Civil use of depleted uranium☆

Maria Betti *

European Commission, Joint Research Centre, Institute for Transuranium Elements, P.O. Box 2340, 76125 Karlsruhe, Germany

Abstract

In this paper the civilian exploitation of depleted uranium is briefly reviewed. Different scenarios relevant to its use are discussed in terms of radiation exposure for workers and the general public. The case of the aircraft accident which occurred in Amsterdam in 1992 involving a fire, is discussed in terms of the radiological exposure to bystanders.

All information given has been obtained on the basis of an extensive literature search and are not based on measurements performed at the Institute for Transuranium Elements.
© 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Uranium; Depleted uranium; Civilian uses

1. Introduction

Uranium is a naturally occurring, ubiquitous heavy metal found in various chemical forms in all soils, rocks, seas and oceans. It is also present in drinking water and food. Natural uranium consists of a mixture of three different isotopes: ^{238}U (99.27% by mass), ^{235}U (0.72%) and ^{234}U (0.0054%).

On average, about 90 μg exist in the human body from the normal intake of water, food and air; of which 66% is found in the skeleton, 16% in the liver, 8% in the kidneys and 10% in other tissues (Priest, 1990).

Uranium is used primarily in nuclear power plants; most reactors require uranium

---

* Corresponding author. Tel.: +49-7247-951-363; fax: +49-7247-951-186.
  E-mail address: betti@itu.fzk.de (M. Betti).
☆ Paper presented at the Expert-Meeting on 'Depleted Uranium in Kosovo: Radiation Protection, Public Health and Environmental Aspect', Bad Honnef, Germany, 19–22 June 2001.

in which the ^{235}U content is enriched from 0.72 to about 3–4%. The uranium remaining after removal of the enriched fraction is referred to as depleted uranium (DU). DU typically contains about 99.8% (by mass) of ^{238}U, 0.2% of ^{235}U and 0.0006% of ^{234}U. For the same mass, depleted uranium has about 60% of the radioactivity of the natural uranium (AEPI, 1995; Cantaluppi and Degetto (2000).

When reprocessed uranium from nuclear spent fuels is used as feed material in enrichment plants, the depleted fraction may contain ^{236}U (*ca.* 3×10^{-3} wt%) together with very small amounts (10^{-7}–10^{-9} wt%) of transuranic elements (plutonium, americium and neptunium) and fission products. In this case, the increase in radiation dose from the trace amounts of these additional elements is less than 1%. In light of the present knowledge, this is insignificant with respect to both chemical and radiological toxicity (WHO, 2001).

According to the International Basic Safety Standards agreed by WHO in 1996, for occupational exposure, the effective dose should not exceed 20 mSv/a averaged over five consecutive years, or an effective dose of 50 mSv in any single year. The equivalent dose to the extremities (hand and feet) or skin should not exceed 500 mSv a year.

For exposure of the general public the effective dose should not exceed 1 mSv/a; in special circumstances, the effective dose can be limited to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mS/a. The equivalent dose to the skin should not exceed 50 mSv/a.

2. Uses of depleted uranium

Depleted uranium has a number of civilian applications. It is employed in counterweights or ballasts in aircraft; radiation shields in medical equipment; as containers for the transport of radioactive material and as chemical catalysts. DU has also been used in glassware and ceramics (as cooking and serving containers) and dentistry.

In addition, depleted uranium has military applications due to its physical properties (e.g. high density that is about twice that of lead). DU is used in munitions designed to penetrate armour plates and is also used to reinforce military vehicles, such as tanks.

Since this review focuses on the civil uses of DU some representative scenarios will be considered.

2.1. Glassware and ceramics

Uranium compounds were used in the coloring of ceramics and glass until the middle of the 20th century. Gamma and beta radiation exposure measured at 1 cm from the surface of natural uranium-glazed ceramic dinnerware samples ranged between 3.1 and 9.2 mR/h (19–56 μSv/h) (Sheets and Thompson, 1995). According to assumptions made by the US NRC, normal use of such items could result in an effective dose equivalent of about 0.07 mSv/a (7mrem/a) from external exposure (NUREG-1717, 1999).

Twenty percent of 15 uranium-glazed dinnerware samples tested contained easily removable surface compounds of natural uranium (Sheets and Thompson, 1995). Vinegar leached up to 30 µg/l of uranium from glass. From a uranium-glazed plate, vinegar could leach up to 31,800 µg/l of uranium, and nitric acid leached 304,000 µg/l of uranium (Landa and Councell, 1992). Based on these leaching and certain consumption rates assumed by the US NRC, an individual could ingest approximately 0.21 g of uranium during 1 year. Thus, given an ingestion factor of 1.9 mSv/g adopted by NRC, this would correspond to an annual effective dose equivalent of about 0.4 mSv (40 mrem) from ingestion of uranium leached from glazed ceramic tableware (NUREG-1717, 1999).

Depleted uranium has been and is still used as the basis of a yellow enamel powder used in the manufacture of badges and jewelry (NUREG-1717, 1999). By γ-spectrometry monitoring (CRII-RAD, 1999) a uranium concentration of 10% was found in the powder; the uranium was depleted to 0.23% uranium-235. The dose rate at the surface of the powder was 8 µSv/h. Jewelry pieces identified as being made with this enamel powder were enamel plates, pendants and rings. The dose rate at the surface of the jewelry pieces was 6.7 µSv/h. For the handicraft-artists using the powder for manufacturing enamel jewelry, the powder presents an inhalation hazard. The effective dose from inhalation of 1 mg powder containing 10% uranium depleted to 0.2% is 11 µSv. The 20 mSv annual standard for workers is equivalent to 1.82 g. This would correspond to a dust concentration in the air of 0.63 mg/m³. If the uranium were recycled from spent fuel, the inhalation dose from 1 mg would be 17 µSv. The annual dose limit of 20 mSv for workers would be equivalent to 1.18 g, and that (based on ICRP68 dose factor for insoluble compounds, breathing rate of 1.6 m³/h, working time 1800 h/a, burn-up of 39 GWd/tHM, storage time of 5 years after unload, tails from enrichment to 3.5%) would correspond to a dust concentration in the air of 0.41 mg/m³.

The measured dose rate at the surface of enamel jewelry containing depleted uranium was 6.7 µSv/h. Assuming that 1% of the skin would be irradiated, this could cause a skin dose of 0.587 mSv/a for a continuous exposure. Applying the ICPR60's tissue weighting factor for skin of 0.01, this results in a committed effective dose of 5.87 µSv/a.

2.2. Dentistry

Up to the early 1980s, natural and depleted uranium was widely used for dental porcelains to obtain a natural color and fluorescence of dentures and the superficial part of crowns. Later uranium was replaced by rare earth elements, such as cerium, terbium, dysprosium and samarium.

As source term, it has been found out that 15 types of porcelain powder of one manufacturer contained uranium in concentrations ranging from 170 to 13,300 mg/kg (0.017–1.33 wt%) (Noël et al., 1988). Moreover, uranium concentrations of 0.5–24.7 mg/kg were found in eight types of porcelain powders marketed in Sweden (Sairenji et al., 1982).

The workers manufacturing denture are exposed to inhalation of powder dust. The

whole-body dose for a technician working in a room in which porcelain powder (containing 0.05% of uranium by weight) is lost during tooth construction, was estimated to be 0.02 µSv (2 µrem), when conservative assumptions for the concentration of uranium dust in air and exposure time (NUREG/CR-1775, 1980; NUREG-1717, 1999) were made.

For persons with dentures, NCRP 95 estimated an annual dose equivalent from beta particles of 5 mSv (0.5 rem) at 0.02% (200 mg/kg) by weight of uranium. On the basis of a weighting factor of 0.01 for the human skin, and assuming that irradiation of the basal mucosa is equivalent to irradiation of 1% of the skin, the effective dose equivalent was estimated to be 5×10^{-4} mSv (0.05 mrem) (NCRP 95, 1987; NUREG-1717, 1999). The annual dose equivalent from alpha particles at the surface of the teeth ranged from 1 to about 4 Sv (100–400 rem) for teeth containing 0.05% of uranium by weight. However, since the maximum range for alpha particles in tissue is about 30 µm, the entire dose would be received by superficial cells on the surface of the mouth and would not reach the radiosensitive cells in the basal layer of the tissues (NUREG/CR-1775, 1980; NUREG-1717, 1999).

2.3. Chemical catalyst

It is known, although not very much information can be found in the literature, that uranium has also been used as a catalyst in certain specialized chemical reactions and in photographic films. The oil and gas industries continue to use nickel-U material (10–65% DU) in relatively large quantities as a catalyst.

2.4. Radiation shielding

The density of DU makes it a suitable material for the shielding of gamma radiation. Therefore it has been used extensively in the medical, research and transport sectors as radiation beam collimator and container for the transport of radioactive sources (NUREG-1717, 1999). The nuclear industry has also used small quantities of DU to chemically absorb gaseous tritium for the purpose of transportation and as shielding in the production of plutonium (Heung, 1995).

DU has been often used as a shield for radioactive sources in tele-therapy units used in treatment of cancer and in linear accelerators. The typical amount used is in the order of hundreds of kilograms. Currently DU is used for vitrified high-level waste packages (Yoshimura et al., 1995) and depleted uranium silicate glasses are used as backfill for spent nuclear fuel waste (Pope et al., 1996). Recently, casks used for holding spent nuclear fuels in the nuclear power industry have been constructed by combining DU with concrete, for example, DUCRETE™ (Starmet, 2001). This achieves a significant increase in gamma-radiation shielding with thinner walls and much lighter casks than the traditional storage ones.

2.5. Counterbalance weights and ballast

Vessels and equipment, such as boats and satellites require large weights to be carried in the form of a ballast. The high density and the availability of DU make

it a potentially suitable material for this purpose. Industries in which the use of DU has been cited for this purpose include: aircraft, military aerospace and boat industries, as well as oil and gas exploration and production industries (NUREG-1717, 1999; Priest (2001).

DU counterweights have been used in commercial aircraft on rudders, outboard ailerons (wing assembly) and outboard elevators (tail assembly). Counterweights come in a variety of weights and shapes, and numerous weights and shapes are used in some aircraft. DU counterweights have been used primarily on wide-body craft. During the past 20 years, DU has been replaced by tungsten (NUREG-1717, 1999). Since 1981, The Boeing Company has installed tungsten counterweights in new Boeing 747 aircraft (Gallagher, 1994). In 1988, McDonnell-Douglas discontinued using DU counterweights and began using tungsten.

It is unknown how many DU counterweights are currently installed in aircraft. It is estimated that approximately 15,000 weights may be associated with the Boeing 747 fleet (Gallagher, 1994). However, the number of aircraft that contain DU counterweights is decreasing. In Table 1 the total weight of DU counterweights for three types of aircraft is reported (NUREG-1717, 1999).

2.5.1. Exposure of workers

Exposure of aircraft workers takes place during the installation of DU counterweights. In this case, the annual dose equivalent to workers responsible for the installation, storage, and transport of DU counterweights was estimated to be 0.2 mSv/a (20mrem/year). The estimated collective effective equivalent dose (EDE) to airline maintenance workers is 0.09 person-Sv (0.9 person-rem) (NUREG-1717, 1999).

Exposure of workers can occur due to inhalation of DU dust after aircraft accidents involving fire. In the case of inhalation of DU dust after an aircraft accident involving fire, the EDE estimated for a fireman is 0.3 mSv (30 mrem) and for a clean-up worker 4 mSv (400 mrem) (NUREG-1717, 1999). The amount of material involved is 850 kg of DU, the amount on a typical Boeing 747 aircraft.

2.5.2. Exposure of aircraft crews and passengers

External radiation from DU counterweights can occur during flight. The annual estimated individual EDEs to flight crews, attendants, and passengers were 0.002 mSv (0.2 mrem), 0,02 mSv (2 mrem), and 1×10^{-4} mSv (0.01 mrem), respectively.

Table 1
Use of DU counterweights in US domestic aircraft (NUREG-1717, 1999)

Aircraft type	Manufacturer	Aircraft number owned by Domestic carriers	Total Weights of Counterweights Per Aircraft (kg)
DC-10	McDonnell-Douglas	168	≅1000
L-1011	Lockheed	60	≅680
B-747	Boeing	201	≅850

The doses to the flight personnel and passengers attributed to the DU counterweights are less than 0.001% of their doses from cosmic radiation (NUREG-1717, 1999). For the estimates, it is assumed there is about 300 kg of DU located in the outboard elevator (tail assembly) and 350 kg of DU located in each aircraft wing. The annual exposure durations assumed were 1000, 500 and 3 h for flight crews, attendants, and passengers, respectively.

2.6. Accidents involving crash of aircraft bearing DU counterweights

In aircraft, DU is only a hazard in the event of high-temperature fires that can arise after a crash. Extensive tests by the US Navy and NASA show that temperatures in jet aircraft fuel-pool fires can reach 1200 °C, and fires with temperatures in the range of 800–1100 °C are common. Such temperatures are high enough to cause very rapid oxidation of DU (Parker, 1988).

The Boeing 747-258F that crashed into a block of flats in Amsterdam in October 1992 carried 282 kg of DU counterweights. The Boeing-747 that crashed near Stansted airport in England in January 2000, was estimated to be carrying *ca*. 425 kg of DU counterweights (Uijt de Haag et al. (2000). In the case of the 1992 Amsterdam plane crash, data recently presented (Uijt de Haag et al. (2000), confirmed that 152 kg of the DU from the crashed plane remained unaccounted for. This does not necessarily mean that this quantity entered into the local environment, as some of the material might have been removed during general clean-up operations of the site that involved the removal of significant quantities of top soil.

The potential radiological exposure (1 h exposure) to bystanders was calculated (Uijt de Haag et al. (2000). Two scenarios were considered: (1) a worst case where all of the missing DU (152 kg) was oxidized into a insoluble respirable fraction; and (2) a less pessimistic scenario, where only 46 kg of the DU was oxidized during the fire and only 1% of this was in respirable form. Modeling of the airborne dispersion based on these cases resulted in atmospheric levels in the area in which bystanders were present of 2000 $\mu g/m^3$ (worst scenario) and 3 $\mu g/m^3$ (best scenario). It was concluded that it was highly improbable that the exposure of bystanders to uranium would result in any of the health complaints reported (Uijt de Haag et al. (2000).

3. Conclusions

Uranium (depleted or not) is chemically toxic, slightly radioactive and, in certain forms, a fire hazard, because it may spontaneously combust on exposure to air. However, when suitable precautions are taken, the civilian use of DU poses only minor health risks. Further research should be performed in areas that would allow better health risk assessment to be made.

References

AEPI, 1995. Health and environmental consequences of depleted uranium use in the US Army. Technical report. US Army Environmental Policy Institute, Atlanta, June 1995.

Cantaluppi, C., Degetto, S., 2000. Civilian and military uses of depleted uranium: environmental and health problems. Annali di Chimica (Rome) 90, 665–676.

CRII-RAD, 1999. Available from <http://www.criirad.com>

Gallagher, T.D., 1994. Radiation safety officer, senior manager, corporate radiation health protection, The Boeing Company. Letter to P. A. Schofield, Oak Ridge National Laboratory. 'Boeing use of DU counterweights in aircraft'.

Heung, 1995. Tritium transport vessel using depleted uranium. DOE Contract AC0989SR18036. NTIS order number DE95010979.

Landa, E.R., Councell, T.B., 1992. Leaching of uranium from glass and ceramic foodware and decorative items. Health Physics 63, 343–348.

NCRP 95, 1987. Radiation exposure to US population from consumer products and miscellaneous sources. National Council on Radiation Protection and Measurements.Report No. 95.

Noël, A., Goengrich, A., Louis, J.P., 1988. Céramique dentaires et radioactivité. Radioprotetion 23, 291–300.

NUREG/CR-1775, 1980. Environmental assessment of consumer products containing radioactive material.

NUREG-1717, 1999. Systematic radiological assessment of exemptions for source and by product materials. Draft Report for Comment, US Nuclear Regulatory Commission, Report 1717.

Parker, R.L., 1988. Fear of flying. Nature 336, 719.

Pope, R.B., Forsberg, C.W., Ashiline, R.C, DeHart, M.D.M, Childs, K.W, Tang, J.S., 1996. DOE Contract Number AC596OR22464. NTIS Order Number DE96008810.

Priest, N.D., 1990. The distribution and behaviour of metals in skeleton and bodies: studies with bone seeking radionuclides. In: Priest, N.D., Van de Vyver, F. (Eds.), Trace Metals and Fluride in Bones and Teeth. CRC Press, Boca Raton, pp. 83–140.

Priest, N.D., 2001. Toxicity of depleted uranium. The Lancet 357, 244–246.

Sairenji, E., Söremark, R., Noguchi, K., 1982. Uranium content in porcelain denture teeth and in porcelain powders for ceramic crowns. Acta odontologica Scandinavia 40, 333–339.

Sheets, R.W., Thompson, C.C., 1995. Accidental contamination from uranium compounds through contact with ceramic dinnerware. Science of the Total Environment 175, 81–84.

Starmet, 2001. www.starmet.com

Uijt de Haag, P.A., Smetsers, R.C., Witlox, H.W., Krus, H.W., Eisenga, A.H., 2000. Evaluating the risk from DU after the Boeing 747-568F crash in Amsterdam. Journal of Hazardous Material 76, 39–58.

WHO, 2001. Depleted Uranium, Fact Sheets No 257, April.

Yoshimura, H.R, Gildea, P.D., Bernard, E.A., 1995. DOE Contract AC0494AL85000. NTIS Order Number DE96007424.