

## DEPLETED URANIUM

### *Introduction*

The element uranium is quite widely distributed in the environment in many natural materials, as can be seen from the following table:

PHYSICAL ENTITY	ABUNDANCE ( $\mu\text{g kg}^{-1}$ )
Solar System	0.2
Sun	1
Meteorite (carbonaceous)	10
Crustal Rocks	1800
Sea Water	3.3
Stream Water	0.04
Human	1

The type of uranium that exists in low, but widespread, abundance in the general environment is known as natural uranium. Its oxide form was first separated from the natural material pitchblende by the German chemist Martin Klaproth as long ago as 1789. For a long time the element remained of no great scientific interest apart from its oxides and salts which were known to be strongly coloured and so were used for the production of attractively glazed pottery coloured glassware. However, this situation was soon to change.

One of the other essays in this series entitled 'Discovery of Radioactivity' describes the classic story of how Henri Becquerel's discovery of the fogging of photographic film by uranium compounds led to the unravelling of the structure of the atom and its component parts; the electron, proton and neutron. Another essay in this series entitled 'After the Discovery of the Nucleus' describes the pivotal role of the isotope  $^{235}\text{U}$  in the discovery of the fission process which in turn led to the development of the atomic bomb, and then to the commissioning of nuclear-fuelled power stations. By the 1950s very few people on the planet were unaware of the spectacular properties of uranium, as on the one hand

promises of a new era of inexhaustible supplies of energy were tempered with newsreel pictures of the series of atmospheric tests of increasingly powerful nuclear weapons.

The objective of this essay is to understand what is meant by the term depleted uranium. We shall look at how it is produced, its chemical and physical properties, how it is measured, what it is used for, and then some topical issues related to the health risks that are involved in its usage.

### ***Isotopes of Uranium***

Natural uranium consists of three isotopes,  $^{238}\text{U}$ ,  $^{235}\text{U}$ , and  $^{234}\text{U}$ , all of which are radioactive with very long half lives. Natural uranium has the following average relative composition by mass;  $^{238}\text{U}$  (99.27%),  $^{235}\text{U}$  (0.72%), and  $^{234}\text{U}$  (0.0054%). It is the variation in the proportion of the  $^{235}\text{U}$  relative to the  $^{238}\text{U}$  that defines whether the uranium is 'depleted', 'natural', or 'enriched' uranium. When the proportion of  $^{235}\text{U}$  is greater than 0.72% by mass we have 'enriched' uranium. When the proportion of  $^{235}\text{U}$  is less than 0.72% by mass we have 'depleted' uranium (DU).

$^{235}\text{U}$  is the only one of the three isotopes that is fissionable by neutron capture. Enriched uranium releases more energy than the same amount of natural uranium, and so it is used as fuel for civil nuclear power stations, and for the production of nuclear weapons. The production of uranium fuel for reactors involves an enrichment process. The uranium used in the world's reactors is enriched in  $^{235}\text{U}$  to the general order of 2% to 5% by mass. DU is a by-product of this process in which the proportion of  $^{235}\text{U}$  by mass is typically 0.2% to 0.3%. DU can also be obtained from the reprocessing of uranium fuel. In this case there will be isotopes of higher mass number present such as  $^{237}\text{U}$ , and small amounts of  $^{237}\text{Np}$  and  $^{239}\text{Pu}$ .

### ***Physical Properties***

Uranium is a silver white metal at ordinary temperatures and pressures, regardless of whether it is depleted, natural, or enriched. One very interesting feature of its physical

properties is that its density of approximately  $19 \text{ g cm}^{-3}$ . It is, therefore, nearly twice as dense as lead! This fact is very relevant to the section on the uses of DU that are discussed later.

## **Radioactivity**

All three of the radioactive isotopes that make up uranium decay by ejection of an alpha particle from their nuclei. In turn, this gives rise to radioactive daughters which decay to other radioisotopes, and so on until the stable element lead is produced. At any one time, a uranium containing substance will contain radioactive isotopes of elements other than uranium, and alpha particles, beta particles (high energy electrons) and gamma rays will be being emitted from within it. The primary unit used to measure the amount of radioactivity is the Becquerel (Bq). If an isotope has an activity of 1 Bq this means that on average one of its nuclei disintegrates every second. The activity per gram is known as the Specific Activity and for natural uranium this is approximately  $25\,000 \text{ Bq g}^{-1}$ . The Specific Activity of the type of DU that forms the topic of this essay is about  $14\,000 \text{ Bq g}^{-1}$ . This difference in specific activity is the major difference between the natural, depleted, and enriched forms of uranium.

## **Pyrophoricity**

Uranium in the form of finely divided powder exhibits the property of being spontaneously combustible in air. This is known as pyrophoricity and is also very relevant to the section on the uses of DU to be discussed later.

## **Chemical Properties**

Pure uranium metal is quite reactive chemically. In the terrestrial environment uranium exists mainly in the form of oxides. Its minerals have the general chemical form  $\text{U}_3\text{O}_8$  and are, in the main, very insoluble in water. However, it is well known that some commonly occurring natural substances do form complexes with uranium which are much more soluble. For example, exposure of uranium to carbon dioxide and water leads to the

formation of a highly soluble carbonate complex. It is in this chemical form that uranium exists in seawater.

## ***Uses of DU***

### **Counterweight in aircraft tailplanes**

In the recent past large passenger aircraft such as the DC-10 and Boeing 747 have employed depleted uranium counterweights in the tail plane to ensure flight control and stability. Its extremely high density means that a lot of weight can be accommodated into the aircraft's structure where space is always at a premium.

### **Radiation Shielding**

Lead (atomic number  $Z = 82$ ) is normally used within the nuclear industry for shielding purposes. Uranium has an atomic number  $Z = 92$  and is much denser than lead, so it has much better shielding properties. It is used extensively in the medical sector as a shield for radiological equipment, for radioactive sources, and in teletherapy units used in the treatment of cancer. It is used to make storage flasks for nuclear waste, and to make flasks for the safe transport of highly active radiation sources that are used in the medical and engineering sectors.

### **Armour piercing projectile for military use**

The very high density of uranium and its pyrophoricity make it a very effective military weapon. Different types of projectiles have been developed. They are particularly effective when used as anti tank munitions. When a high velocity uranium projectile hits a solid target such as tank armour it will be brought to rest and transfer its energy into the target. This often results in a complete destruction of the target as the steel is literally shredded into thousands of fragments by the force of the impact. At the same time part of the uranium projectile is vaporised into particles of extremely small diameter which ignite in the high temperatures resulting from the impact.

## ***Measuring Uranium***

### **How it is measured**

Uranium can be measured in several ways. The beta and gamma radiation emitted by uranium may be detected using traditional instruments such as a Geiger counter. One of the traditional methods utilises the property of fluorescence that is exhibited by compounds such as uranium fluoride. X-ray fluorescence is a useful technique used today for determining the mass of uranium present, particularly in solid materials. However it does not provide information on the uranium isotopic content and so can not be used to identify depleted uranium. Isotopic analysis requires chemical separation of uranium from the sample matrix. Two of the more commonly used methods will now be described.

### **Alpha spectrometry**

This is a radiometric technique, i.e. it is a technique that measures the ionising radiations that emerge from the uranium as a result of the decay of its nuclei. In this case the alpha particles are measured. Because of the different half-lives and mass abundances of the three isotopes this technique is particularly good for enabling the  $^{238}\text{U}$  and the  $^{234}\text{U}$  isotopic activities to be determined. Alpha spectrometry techniques are typified by being quite labour intensive. Sample turn-round times of 24 hours can be achieved for liquid samples, but more typically this will be in excess of three days for samples such as soil and sediment. A considerable amount of chemical processing is needed to separate the uranium from the elements present within the sample matrix. Additionally the uranium source has to be prepared as a very thin layer. If not most of the alpha particles will be absorbed within the source itself Remember that uranium is nearly twice as dense as lead. The long half lives of the uranium isotopes has another consequence for this technique, i.e. at very low activity levels counting times of days need to be used to collect a sufficiently large number of alpha particles to keep the precision of the measurement reasonably low.

### **Mass spectrometry**

Mass spectrometric techniques have long been used for making uranium isotopic analyses. One variant making rapid advances today in analytical chemistry is the Inductively Coupled Plasma Mass Spectrometer (ICP-MS). In these techniques it is the uranium isotope ions that are counted by the spectrometer. One limiting factor affecting sensitivity and limit of detection here is the mass abundance of the isotope and not its radiation decay half life. There are over  $10^{15}$  atoms of  $^{238}\text{U}$  in 1 g of ordinary soil, and if all of them could be ionised and collected mass spectrometry would be a very highly sensitive technique. Technical difficulties with the instrumentation limit the number of ions collected but ICP-MS is more sensitive than alpha spectrometry for making measurements of  $^{238}\text{U}$  and  $^{235}\text{U}$ . Samples are normally injected into the spectrometer's plasma flame in liquid form and the resulting ions which are formed are collected within 1 minute from which the  $^{238}\text{U}$  and  $^{235}\text{U}$  activities are calculated. The ICP-MS is capable of very rapid sample throughput.