DEPLETED URANIUM MUNITIONS: New Weapons of indiscriminate and Mutually Assured Destruction

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I am grateful to Technology for Life for the invitation to give this lecture on depleted uranium, DU, and its use in modern warfare as part of the United Nations Peace Celebrations.

1. INTRODUCTION

Uranium, U, is a primordial element as old as the earth and is the naturally occurring atom with the highest atomic mass and atomic number. It is heavy, unstable, and chemically reactive (the pure metal is pyrophoric) and occurs naturally as a mixture of radioisotopes which form part of the uranium and actinium series. These properties are encoded, for U-238, in the following chemical notation.

238 ← **ATOMIC MASS HEAVIEST NATURAL ELEMENT**

92 ← **ATOMIC NUMBER (Z) UNSTABLE**

U-238, at the head of the uranium series, decays with the emission of α, β–, particles and γ radiation, through 14 radioactive intermediates, including U-234, to a stable isotope of lead, Pb-206. Whilst U-235, at the head of the actinium series, decays through 11 radioactive intermediates to another stable isotope of lead, Pb-207.

Naturally occurring uranium is therefore composed of many different isotopes and elements and is present, on average, at around 1-3 ppm (parts per million) in the earth's crust. Its natural ores, pitchblende is the best known, contain 0.02-0.2% uranium and has been mined in several countries including Canada, USA, Namibia, S. Africa, Russia and Australia. The latter is now the major world producer.

Uranium is both a radiological and heavy metal poison. The latter property approximates to that of lead a known neurological poison. Uranium has no known role in any biological system.

PROCESSING FOR COMMERCIAL PURPOSES

Uranium ore has to be extracted and processed to obtain uranium containing an increased amount of U-235 which is isotope required for military (nuclear weapons) and civilian (nuclear reactors) use.
The manufacturing processes alter the levels and ratios of the natural isotopes and daughter molecules which means that for our purposes it is only necessary to consider U-238, U-235, U-234 and, for radiochemical reasons, the U-238 decay products, Th-234 (Thorium-234) and Pa-234 (Protoactinium-234).
Essentially the ore is converted, via uranium oxide, $U0_2$, to uranium hexafluoride, UF_6, a solid which becomes a gas above 57 ^oC and enables the separation of the different uranium isotopes by a process of gaseous diffusion. The relative abundances (%) of the uranium isotopes in the natural starting material, enriched uranium, and the waste, depleted uranium, are given in Table 1. These figures can vary by +/- ~10%. The half-life is the time taken for the original material to degrade by 50%.

ISOTOPE	NATURAL	DEPLETED	ENRICHED	HALF-LIFE, $t_{1/2}$
U-238	99.2749 %	99.7947 %		4.49×10^9 years
U-235	0.7196 %	0.2015 %	3.2-3.6 %	7.1×10^8 years
U-234	0.0055 %	0.0008 %		2.48×10^5 years

Table 1. The % Abundance of the important Isotopes in Natural, Depleted, and Enriched Uranium.

Typically, 11.9 metric tons of uranium hexafluoride (equivalent to 8.05 tonnes of uranium) will yield 1.48 tonnes of enriched uranium hexafluoride (1 tonne enriched uranium) and 10.42 tonnes of waste, depleted uranium hexafluoride (7.05 tonnes DU).
Seven times more waste than enriched product is obtained. There is a crucial waste problem.
The long half-lives of all the naturally occurring isotopes of uranium mean that they are with us forever.

THE WASTE PROBLEM
Depleted uranium hexafluoride has to be stored as low level nuclear waste. This requires expensive storage facilities which will not degrade and liberate the waste. Uranium hexafluoride is highly reactive chemically and with water gives, the corrosive and poisonous, hydrofluoric acid and uranium oxide difluoride. It is not a suitable form for long-term storage. Nevertheless most stored material is in this form. A storage cylinder is shown, Figure 1, and a stockpile of rusting cylinders in Figure 2.
Some 750,000 tons (2000 pounds- USA/Canada ton) are presently in store with a further 1,900 tons added annually. A huge problem.

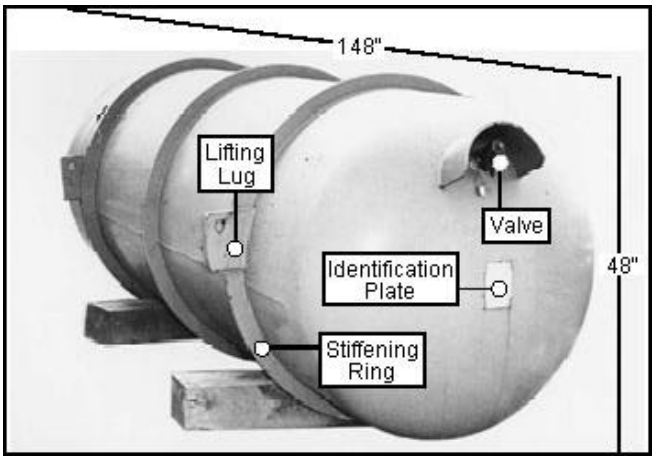


Figure 1. Storage cylinder for Uranium Hexafluoride

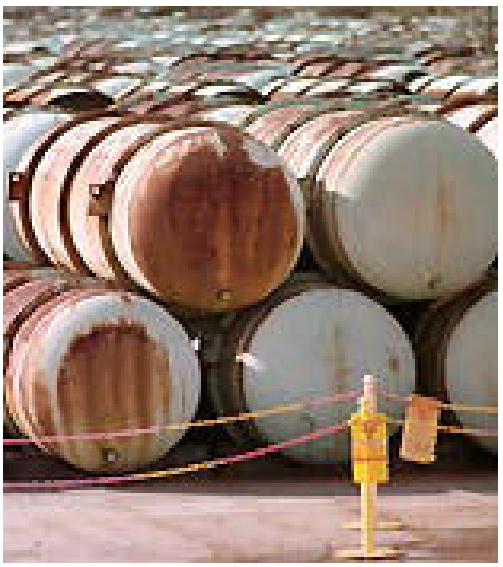


Figure 2. Rusting Cylinders stored in the open

Depleted uranium hexafluoride is further processed to obtain the metal, DU, which is used in the manufacture of a range of munitions-see below.

RADIOACTIVITY

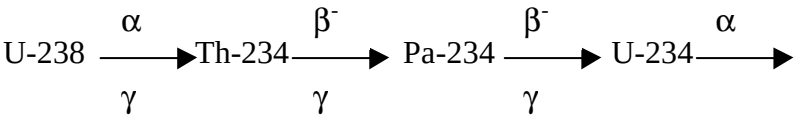
When radioactive elements decay they emit a variety of particles and rays. The principle particles and rays that we are concerned with are listed in Table 2.

Table 2. The Particles/Rays emitted by U-238 and U-235 during their Radiochemical Decay.

Particle/Rays	Charge/Mass	Energy	Velocity	(Penetration Ratio)*	RBE-factor**
α	He^{2++} 6.696×10^{-24} g	4.2 MeV	~5% of light	(1)	20
$\beta-$	an electron - negative 9.109×10^{-28} g	2.29 MeV	~3-99% of light	(100)	1
γ rays	none but ionising	~850 keV (>40 KeV)	~velocity of light	(10,000)	1

* Penetration Ratio is a measure of the relative penetrating power of the different particles and rays. α–Particles have low penetration and are easily screened when the source is **outside** the body. It is more difficult to screen the smaller and faster $\beta-$ particles and γ rays.
** Relative Biological Equivalence Factor: This is a weighting factor which indicates the relative capacity to damage biological tissues. α–Radiation is much more damaging than other forms of radiation when it is **inside** the body

The energies given are those for the particles and rays emitted during the decay of the uranium isotopes. All this radiation is ionising radiation and generates ions and free radicals in the medium through which it passes. This is high energy radiation. [There are a range of values for particles and rays from other radioisotopes.]



The isotope ratios in DU are disturbed by the manufacturing process but on storage (20-30 weeks) a secular equilibrium is established in which there are an equal number of disintegrations per second for U-238 and its daughter isotopes, Th-234 and Pa-234, Table 3. Only a very small amount of U-234 is present in DU.

Table 3. Radioactivity (disintegrations per second) in **1 mg** of U-238 at Secular Equilibrium.

U-238	Th-234	Pa-234	U-234
12.4	12.4	12.4	0.017

This is equivalent to 390 million α–particles, 780 million β–particles and the associated γ–rays in 1 year - over 1 billion high energy, ionising, radioactive particles and rays which can produce extensive biological damage. The energy of each α–particle vastly exceeds that required for damaging important biological macromolecules such as DNA, RNA, enzymes and proteins. By breaking bonds within them, and water molecules, novel chemical reactions which alter or destroy the shape, organisation and function of these molecules are initiated.

RADIOACTIVITY MEASUREMENTS AND UNITS

The variety of different systems and the complex definitions and nomenclature make for confusion and misunderstanding. The following are commonly used:-

Bequerel, Bq disintegrations per second, dps. [The Curie, Ci, is a common alternative. 1Ci = 3.7x 10^{10} dps]. It is important to state the mass of the radioactive source, see Table 3.

Radiation Absorbed Dose, **rad**, is the amount of the energy absorbed following exposure to radiation. 1 rad = 100 ergs of energy absorbed per gram of tissue. It is NOT the total dose. The rad has now been replaced by the **Gray, Gy; 1Gy = 100 rads.** It is crucial to know the amount of tissue being exposed as well as the number of Gray or rad.

The Equivalent dose is important when trying to assess the **biological effects of different types of radiation**. The radiation absorbed dose is multiplied by a quality factor, RBE, - see Table 2. The resulting unit is the **rem** (Roentgen Equivalent Man). The preferred unit today is the **Sievert, Sv: 1Sv = 100 rem.**

The Effective dose of radiation is a measure of the **biological effects of radiation on the different types of tissue** being irradiated. It requires a further weighting factor which takes into account the different sensitivities of various tissues to radiation. The thyroid is known to be particularly sensitive.

These different weighting factors were determined from studies of the relative incidence of cancers among Japanese survivors of the atomic bombs. They experienced acute, high dose exposures in the first instance. There is considerable debate about the appropriateness of such figures for exposures to the much lower levels of radiation associated with the military and civilian use of radioactive materials- see below.

KEY FACTORS

1. The **amount** of the radionuclide present is usually expressed in grams, milligrams (1 thousandth of a gram), microgram (1 millionth of a gram), nanogram (1 billionth (ie. a thousand millionth of a gram), picogram (1 billion billionth of a gram). For heavy material like DU and uranium compounds derived from it such particles will be very small indeed.
2. The **type of radiation** emitted during the decay process, see Table 2.
3. The **physical half-life** of the radionuclide - how long does it stay around, Table 1.
4. The **physical and chemical form** of the radioactive material. Is the material **soluble, insoluble**, or **ceramic**? Soluble material will move rapidly in the environment and spread relatively quickly. Insoluble material will remain at its initial location much longer and its radiation will affect a smaller area but at higher radiation levels. Ceramic material is very insoluble and will move even more slowly. **Particle size** is very important as this will determine how readily material, particularly insoluble and ceramic particles, can be inhaled and/or ingested.
5. The **biological half-life** of the radioactive material. This is the time taken for the amount of material to be reduced by 50% of the original amount. The longer the biological half-life the longer the material will reside in the body and the greater the cumulative radiological dose. See p. 9ff.
6. The **fraction** of the radioactive material that remains in a particular organ.
7. The **sensitivity** of a particular organ to the radiation emitted.

EXPOSURE LEVELS

Universally agreed levels do not yet exist but there is a growing move towards the levels set by the International Commission on Radiological Protection, ICRP. The USA has signally failed to endorse these levels and allows much higher exposure levels. Generally there are two different levels for the **public** and **occupational workers.** The

latter are well informed, extensively monitored, wear protective clothing and use procedures which minimise the risk of exposure to radiation. This is not the case with the public. The following are useful reference figures.

The **annual average intake** of uranium is **~ 0.436 mg/year**. This is usually ingested as soluble and insoluble uranium derivatives in food or water and partially absorbed through the gut. It represents an **effective radiation dose equivalent to the whole body** of **0.005 mSv** (a mSv is one thousandth of a Sievert). This is the **background amount**.

Table 4. Maximum Exposure Limits for Inso1uble Uranium for year

	DOSE mSv	MASS mg	x BACKGROUND	AIR**
PUBLIC	1	1.2 (6)*	2.75 (13.75)*	0.14 microgram
OCCUPATIONAL	20	24 (60)	55 (137.5)	0.29 microgram

*Figures for USA in brackets. **Assuming continuous exposure as would apply in the Gulf War theatre.

DU in WARFARE- WEAPONS and ARMOUR

The problem of depleted uranium waste was described earlier. Since the 1970s the USA has been experimenting with and developing DU munitions and armour. DU was chosen for the following reasons.

1. It has a high density, 19.05 g cm^3, which is 1.7 times that of lead. Tungsten has a slightly higher density, 19.3 g cm^3.
2. It is pyrophoric and burns on impact providing a self-sharpening penetrator through conventional armour and other target materials.
3. It is cheaply and readily available. It was supplied cost-free to the arms manufacturers.

The machining of uranium has gives rise to fine swarf which has spontaneously ignited causing fires in heavily populated areas. Civilian fire-fighters often ignorant of the hazards of DU fires and the dusts liberated by them have had to deal with such fires. The public are largely uninformed and unaware of these hazards until a fire has actually occurred.
A huge stockpile munitions now exists from which the weapons used in the Gulf War, Bosnia, and Kosovo were drawn.

Figure 3. The Varieties of DU Munitions available today.

Figure 4. Large DU shells for use in tank warfare.

The weapons used in the Gulf War included 120, 105, 30, 25, and 20 mm rounds for use by tanks, aircraft, naval cannon and machine guns. The different rounds contained from 5,350 to 70 grams of DU. In addition the Cruise Missiles used in attacking major targets in and around Baghdad and other major cities carried DU as counterweights to stabilise their flight. This would burn in the general conflagration when they hit their targets. More recently 3,000 gram of DU has been used in the tips of WDU-36 Tomahawk Cruise missiles fired in Bosnia.

Many of the larger DU weapons have a DU penetrator incorporated in a Sabot Fin round which stabilises flight.

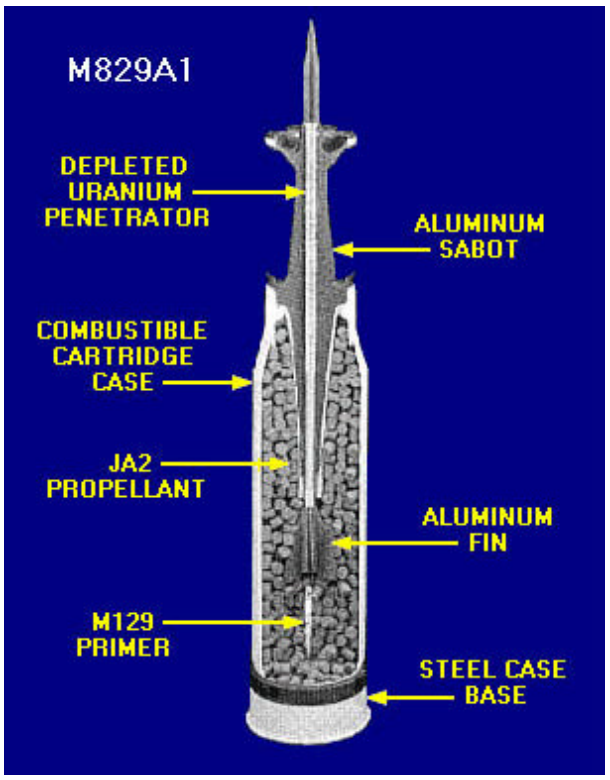
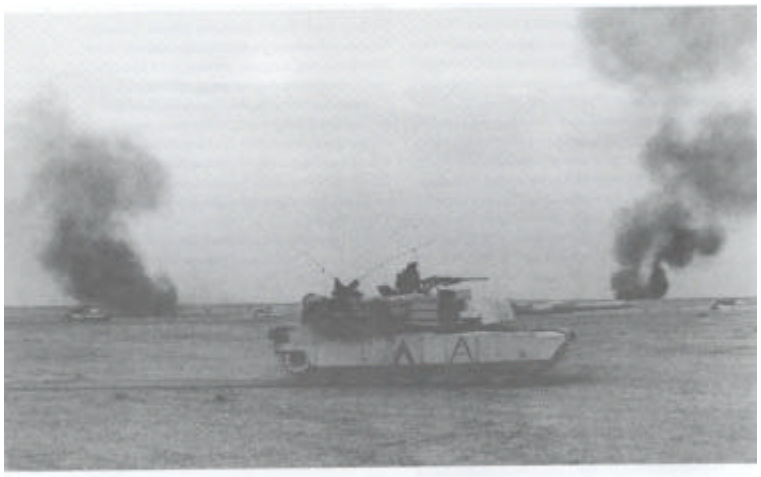


Figure 5. Structure of Sabot Fin Round

Figure 6. Firing a Sabot Fin Round

When a sabot fin round is fired the DU penetrator is released and even if it misses the target will leave the fully exposed DU open to the environment. Handling it will be more hazardous than the complete round in which the various cladding materials will provide a shield, particularly against α–radiation. An estimated 74% of such rounds missed their target in the Gulf War. This represents a considerable radiological and toxicological hazard to the local environment. People and animals will be affected as will the water supply. Children playing with these penetrators would be particularly vulnerable. The degradation of penetrators is known to contaminate water courses and food supplies.
The penetrators that hit their targets would burn and produce a dust aerosol containing oxides of DU in a variety of particle sizes. Figure 7 shows this clearly.



American M1-A1 tank in front of burning T-72s (Iraqi tanks), outside Basra, Iraq, March 1, 1991. M1-A1 tanks are clad with depleted uranium (DU) and fire penetrators made of DU. "Since DU weapons are openly available on the world arms market, DU weapons will be used in future conflicts. The number of DU patients on future battlefields probably will be higher because other countries will use systems containing DU."—from the Army's unreleased report on depleted uranium weaponry

Figure 8. Tank battle with smoke and DU dust/aerosol rising from tanks hit by a DU sabot round.

The dust generated when a DU round hits a solid target consists of an **aerosol of ceramic, soluble and insoluble** oxides of uranium. Between 46 and 96 % of this dust can be in an aerosol form. The exact amount varies depending on the nature of the impact of the penetrator with the target. Some 50-70 % of this dust is in very fine particles, <10 microns (a millionth of a metre, or thousandth of a millimetre) in diameter. Such particles are **readily inhaled** and ingested. The most dangerous particles are <2.5 microns. Particles of this size readily enter deep into the lung tissue and lodge there. They may, if they are insoluble, stay in the lung for years or move slowly to other body sites, particularly lymph nodes, spleen, bone, bone marrow, liver and kidneys. It has been calculated that **a 5 micron particle lodged in the lung for one year would provide 8,000 times the maximum annual dose.**
It is also recognised by the military that when DU shells are fired DU dust will be **released inside the** tank which will contaminate the tank crew, particularly the gunner.
A further property of these particles is the long time that they **remain suspended in the air**. DU was found in the air over Kuwait City in 1993, some **2 years after the Gulf War** ended. **Re-suspension** of DU particles occurs readily with relatively light breezes and/or vehicle and aircraft, especially helicopter, movements.
These particles can also be **transported over long distances**, up to 30 miles, in moderate breezes. There are examples of such transport in the military and civilian literature.
Once DU dust has been released it cannot be controlled nor can its subsequent distribution be predicted. It presents a hazard to combatants and non-combatants, military and civilian, friend and foe alike. It will remain a continuing hazard, in the environment, for many years (tens, hundreds, thousands?) to come.

HOW MUCH DU WAS RELEASED AND WHERE?
Figures vary but it is now clearly admitted in documents and reports from the Pentagon, House of Representatives and Congress that at least 359 tons (the 2000 pounds North American ton) were fired. This includes 59 tons now attributed to the British forces. A figure denied by the Ministry of Defence (88 shell only) but consistent with the photographic evidence of British tanks loaded with DU ammunition (up to 90 shells per tank) and British ammunition transport during the Gulf War.
The independent LAKA Foundation in the Netherlands using soil analysis has estimated that some 800 tons of DU ammunition was used.
Over all some 3,000,000 to 8,000,000 grams (or 3-8 **billion** milligrams) of DU have been released. This vastly exceeds the total annual dose limit for the whole population of the USA and is enough to kill the whole population of the USA. The UK annual public dose limit corresponds to 2 milligram of DU.
The map, Figure 10, covers the immediate battlefield area and show the major areas where DU munitions were used. It does not include any assessment of the DU delivered by Cruise missiles which hit numerous targets in and around Baghdad.
Furthermore, the unpredictable movement of DU dust means that DU will be distributed over a much wider area.
It is important to recognise that no instructions were issued to troops engaged in the ground war about any hazards associated with the handling and firing of DU. Specifically no instructions were given about entering battlefield areas or vehicles where DU had been used. The troops had no protection.

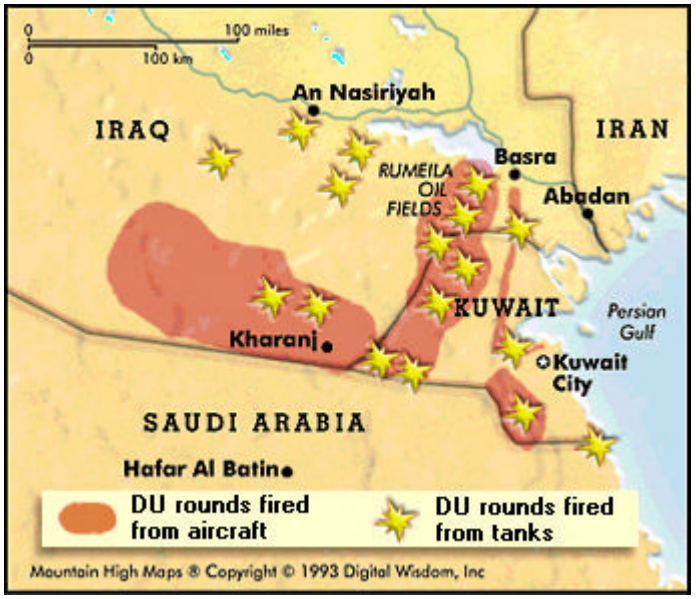


Figure 10. Battlefield Areas where DU is known to have been used.

A very common occurrence were sightseeing trips to the major battlefield sites, by personnel not involved in the frontline battles. Such visits would inevitably expose the unprotected and unsuspecting 'tourists' to possible contamination by DU which would be, at least in part, inhaled.

Figure 11. Sightseeing on the Basra Road

Casualties brought in from the battlefield, particularly Iraqi wounded would also bring DU dust in their clothing and raise the possibility of contamination of personnel in hospital units.
Apart from DU dust there was the likelihood of shrapnel fragments containing DU being released from the penetrator and/or armour in the case of USA vehicles and tanks. One such incident led to a number of USA personnel receiving shrapnel wounds in a 'friendly fire' incidence -p. 10.

The use of DU weapons in Bosnia and Kosovo has been admitted by both the USA and UK Governments but both have refused to say how much DU ammunition was fired, at what targets, and in which places. It has been estimated that the 4,500 kilograms (4,500,000 grams or 4,500,000,000 milligrams) of DU was delivered through the use of the new WDU-36 Tomahawk Cruise missiles alone in Bosnia. Since each missile has 3 kilogram of DU incorporated in its tip. This equates to 1,500 missiles being fired during that conflict.

WHO IS AT RISK?
Everyone who was in or near the theatre of operations, military personnel, civilians, men, women, and children and future generations yet unborn. The whole environment.

CIVILIAN USE
Although the overwhelming use of DU has been in the production of battlefield weapons it has also been used in various civil applications, most notably as a counterweight in large aircraft. The first 550 Boeing 747s contained 1500 kilograms of DU but changes in aircraft design led to this amount being progressively reduced and then finally abandoned. Despite being nickel-cadmium plated these counterweights were found to rapidly corrode. In a major plane crash involving a fire DU dust would be liberated and be a significant health hazard to people in the vicinity, rescue workers and accident investigators. The El Al crash in the Bijlmermeer suburb of Amsterdam was one such incident. I has been calculated that up to 250,000 people could suffer health risks, up to near poisoning, from the DU released following the crash and fire in this heavily populated area. What is indisputable is that there are now many people reporting new symptoms of a variety of diseases which in many ways resemble those of the Gulf War Veterans. Official denials, distortions, and total disregard for the welfare of people marked the whole episode. Throughout this incident the public were totally ignorant of the possible health risks they were exposed to and the secrecy of the Netherlands and particularly the Israeli governments has prevented the full truth of the disaster emerging. The LAKA foundation has described the whole sorry story in its recent booklet.

ASSESSING THE RISKS
There is available a variety of data, mainly from animal studies but including some human studies, that identifies the consequences of exposure to uranium derivatives. The biological effects are usually categorised as acute (up to 15 days), intermediate (15 - 365 days), or chronic (over 1 year) depending on the duration of exposure to the radiological hazard. DU exposures due to warfare will give rise to chronic effects particularly associated with contamination by insoluble inhaled or ingested uranium particles.

Table 5. A Summary of Animal and Human Data on the Chronic Effects of Exposure to Uranium.

SYSTEM/ORGAN AFFECTED	MAJOR EFFECTS (ANIMAL SPECIES)
RESPIRATORY	LUNG FIBROSIS, CANCER * (DOG)
BLOOD/BONE MARROW	LENGTHENED CLOTTING TIME*, BLOOD MONOCYTES DOWN
IMMUNE SYSTEM	LYMPH NODE FIBROSIS, SUSCEPTIBILITY TO INFECTION* INCREASES IN AUTOIMMUNE DISEASES*
CENTRAL NERVOUS SYSTEM	IMPAIRED NEUROCOGNITIVE FUNCTION*
ENDOCRINE CHANGES	DISTURBANCE OF HYPOTHALAMIC-PITUITARY FUNCTION*
MUSCULO-SKELETAL	WEAKNESS*
LIVER	FATTY LIVER*, NECROSIS
GENES AND REPRODUCTION	CANCERS, BIRTH DEFECTS*
GASTROINTESTINAL	IRRITABLE BOWEL SYNDROME* (BLEEDING)
KIDNEY	DEGENERATION*, REGENERATION, LESIONS, NECROSIS

MORTALITY	4.5% * (DOG)

*****Effects reported by Gulf War Veterans

It is important to recognise that these effects can result from many other causes and do not necessarily indicate chronic uranium poisoning, for example fatty liver is associated with excessive alcohol use, birth defects can result from exposure to the mustard gases which were used in the Gulf War. What are required are measurements of the actual levels of uranium and DU in the urine of the people who are sick.

The fact that, "uranium poisoning is characterised by general health impairment", means that medical examinations can be carried out and illness identified which is ascribed to other causes in the judgement of the examining physician. This means that DU is not even considered as a cause of the illness and **the appropriate investigations are not carried out**.

A number of important points need to be emphasised with regard to the biological effects of DU radiation.

1. A major factor is the biological half-life of DU particles inhaled by Gulf War Veterans. Soluble uranium compounds have a biological half-life of ~12-24 hours which means that they are rapidly eliminated from the body following ingestion or inhalation. Insoluble uranium compounds have a half-life of ~500 days showing that they reside in the body much longer. There is practically no data on ceramic uranium particles. Data in rats indicates a much longer half-life which, by extrapolation, is of the order of 10-20 years in man. The fact that some Gulf Veterans are still excreting DU over 8 years after the conflict supports this figure. There is evidence to indicate that about one-third of the inhaled uranium is soluble and rapidly excreted. The remainder persists in the body and will give rise to large cumulative doses of radiation. The body can slowly move uranium particles from the lung to other sites principally the lymph nodes, and bone. The body is able to, very slowly, solubilise insoluble uranium leading to its excretion through the kidneys. This process accounts for the low levels of DU excretion found in the Gulf Veterans.
2. The effects of radiation may be dose-related or random (stochastic). Burns arising from exposure to β–radiation are dose-related. The higher the dose the more damaging the burn. At some point there will be a threshold dose below which burns are not caused. In contrast the effects, particularly of the more internally damaging α–radiation, on gene structure and function are stochastic. There is no limiting threshold dose for these effects which can give rise to cancers in the person exposed and to their offspring. Any exposure may lead to the development of a cancer.
3. In adults the development of radiation induced cancers generally takes 10-20 years. It is therefore spurious and bad science to assert that because of there are no very big increases in cancer rates among adult Gulf Veterans any exposure to DU is not significant. In children, where growth processes are much more active, cancers would be expected to appear much earlier. In Iraq there has been alarming increases in childhood cancers.
4. Genetic damage in the Gulf Veterans will most rapidly be seen in birth defects occurring in their children. There is very strong evidence that this is happening among Veterans and the Iraqi population. For example, among 261 families of Mississippi Veterans there was a 67% incidence of severe birth defects. Siegwart-Horst Guenther has documented the horrendous nature and number of birth defects among Iraqi children in Southern Iraq. Radiation levels in the Rumeila oilfields, Figure 10, were found to be 50 times background values.
5. Although the effects of radiation, particularly α–particles, may be very localised, biological mechanisms in the body are able to transmit, rapidly and effectively, these effects to other areas of the body by , for example, lipid peroxidation or cytokine release. The result is far-reaching changes in many different organs and systems of the body.

OFFICIAL DENIALS

The attitude of the Ministry of Defence, MOD, in the UK and the Department of Defence, DOD, and Veterans' Administration, VA, in the USA has been to vigorously deny the possibility of DU playing any part in the illnesses experienced by Gulf War Veterans. Their stance has ignored or rejected studies reported by the USA Military and reports from civilian studies which clearly show it is important to consider DU contamination as a possible/probable significant factor in the illnesses experienced by the Gulf War Veterans.

Examining physicians in the UK have rejected the possibility of DU being a possible cause of any Gulf Illnesses whilst in USA when investigators have wanted to look for evidence of DU contamination amongst Gulf Veterans their services have been terminated by the VA.

The result has been that there has been no attempt by any official bodies to investigate contamination of any Gulf Veterans by DU.

No studies have been carried out on the Iraqi population. Indeed Iraq only learned of the use of DU ammunition more than 1 year after the Gulf War ended.

Research in this field has been carried out, privately, by a small number of concerned and highly qualified people in Canada and the USA.

The continuing denial of possible large-scale contamination by DU is clearly driven by the Military-Government-Industrial axis which having developed these powerful new weapons now sees a financial 'killing' on the

international arms markets and a way of reducing the large stores of DU. DU munitions, nearly all supplied by the USA, are known to be in the possession of at least 17 countries including Bahrain, Egypt, France, Greece, Israel, Kuwait, Pakistan, Russia, South Korea, Taiwan, Turkey, and the USA.

THE EXCEPTION

The only study carried out by the VA began in 1993! and involved some 33 USA service personnel who had been received shrapnel wounds as a result of 'friendly fire'.

The results of this study were made public at a Conference in Arlington, USA, in September 1998 and have since been published in *Health Physics*, 1999, **77**, 512-519.

The results showed

1. The uranium values for the DU exposed group ranged from 0.01 to 30.74 microgram/gram creatinine. This is one way of measuring the levels of urinary constituents. It can only be approximately compared with the 24-hour urine excretion measured more recently in other veterans and civilians whose excretion levels are of the order of 3-8 micrograms/day
2. Elevated uranium levels correlated with lowered neurocognitive performance.
3. There was a sevenfold mean difference in urinary uranium concentration between the low and high prolactin groups and a threefold difference in urinary concentration between the follicle stimulating hormone, FSH, groups. This indicates a significant endocrine disruption of the centrally controlled reproductive hormones.
4. 5/22 had measurable DU in their sperm. A disturbing observation which indicates the potential for far reaching damage to any offspring.
5. In addition the group reported a number of medical problems; cardiovascular (31%), musculoskeletal (24%), and psychiatric (24%). One member had an active tumour.

Given all this and the high degree of correspondence with the symptoms summarised in Table 5 it is astonishing that no serious investigation of DU contamination in the Gulf Veterans has ever been undertaken.

One survey of some 10,000 USA Gulf Veterans concluded that 4/5 could have been exposed to DU aerosol dust as a result of contact with DU destroyed vehicles. Still no action.

Sergeant Daryll Clark was in a forward position with a radar battery and found his unit surrounded by 20 Iraqi tanks. He called for air support which destroyed all 20 tanks leaving Clark and his unit engulfed in choking smoke from the burned out tanks. Subsequently Clark has developed severe chronic respiratory problems. His daughter, born in September 1992 had no thyroid gland and haemangioma (purple welts) on her skin and internal organs. His urine tested positive for DU in 1994. Still no comprehensive action.

Amongst the families of 251 Mississippi Veterans 675 of children born after the Gulf War have severe birth defects. Still no action.

Indeed the Military and government continue to deny that there is any evidence of increased levels of genetic defects among children born to Gulf Veterans. In the UK a questionnaire epidemiological study to look at birth defects and other reproductive problems will not report for another 1-2 years.

MEASURING DU

One way of avoiding the issue of DU munitions is not to look for any adverse effects from their use. If a long enough period of time elapses the hope could be that the evidence would disappear. This appears to be the strategy of the USA and UK authorities. It is now over 8 years since the Gulf War and no official studies have commenced.

Even with an initial high exposure to DU dust the levels of DU in the urine of most Gulf personnel will be low. Unless the very best methods of measuring DU are used it will be possible to conclude that the uranium now present in the urine of Gulf Veterans poses no significant health risk. One UK Veteran has already been told that this is the case and that his need for a kidney transplant is in no way connected with any possible contamination by DU.

To prove the Veterans' case it is necessary to show that they are still excreting DU and not just natural uranium consumed in food and water. If the presence of DU can be unequivocally established this means that the Veteran was contaminated during the Gulf War as a result of some kind of contact with DU used in the war.

The only analytical method that can convincingly show the presence of DU at the low levels now present in the majority of Gulf War Veterans is **mass spectrometry**. It has a detection limit of 4 picograms and is some 100 times more sensitive than other methods. It also accurately and reproducibly measures the isotope composition of the uranium present in the urine. Using this method

1. **definite contamination of military personnel and civilians has been demonstrated.**
2. **calculations of the estimated initial exposure have been made- these show significant health risks.**
3. **the cumulative radiological dose has been calculated and massively exceeds safe levels.**
4. **increased fatal cancer numbers in the gulf cohorts have been estimated.**

This information that will enable the best possible management of the health of the Gulf Veterans.

THE DU SIGNATURE

The ratio of the U-235/U-238 allows DU to be clearly distinguished from natural and enriched uranium. Table 1 shows the proportion of each of these isotopes in the three types of uranium and Table 6 the corresponding isotope ratios. A variation of +/- 10% is allowed at Los Alamos and gives a band outside of which the identity of DU is indisputable.

Table 6. U-235/U-238 Ratios for Natural, Depleted, and enriched Uranium

NATURAL	DU PENETRATORS	ENRICHED
0.0075 error +/-10% 0.0068 - 0.0082	0.0020 +/-10% 0.0018 - 0.0022	> 0.0085

Los Alamos Laboratory uses a ratio between 0.0065 and0.0085 for Natural Uranium

ANY RATIO <0.0065 SHOWS DU IS PRESENT. ITS SOURCE MUST BE FROM THE MILITARY.

DUPLICATE MASS SPECTROMETRY MEASUREMENTS

US VETERAN	**0.004376/0.0043458**	**~40-50% DU**
UK VETERAN	**0.004322/0.004316**	**~40-50% DU**
IRAQI VETERAN	**0.006349/0.006315**	**~15%**
IRAQI CIVILIAN	**0.006218/0.006211**	**~18%**

Some samples showed no evidence of DU which emphasises the power of the analysis.
In addition U-236 was found in some samples. This isotope is a product of further recycling of DU at a nuclear facility. Russia has such facilities and is known to re-work DU from the USA and possibly UK.

EXPOSURE TO DU UNAMBIGUOUS-NO ARGUMENTS

From the direct measurements of urinary levels of DU it is possible to calculate making a series of reasonable assumptions the initial exposure suffered and the total cumulative radiological dose. Professor Hari Sharma and Dr. Rosalie Bertell have made such calculations and estimated an initial dose of DU was ~42 milligrams corresponding to a whole body radiation dose of 0.778 Sv assuming a 20 year biological half-life.
From this data it is can be calculated that for Veterans excreting 3 microgram per day (the actual figure varies from l<1 to 8 microgram) there is an additional risk factor of 3-21%, ie. for every 100,000 Veterans **additional fatal cancers** will range from 3,000 to 21,000.
If this represents the risk for the whole **UK cohort** of 53,000 then **1,500 to 10,500 additional fatal cancers** would be expected.
For the **USA cohort** of 697,000 some **20,900 to 146,400 additional fatal cancers** would arise.

Whilst it is possible to dispute the assumptions underlying these calculations I believe them to be reasonable and, if anything, to err on the low side. There is no need to exaggerate the potentially massive problems arising from the use of DU munitions in the Gulf War.
It is not possible to overstate the seriousness of this issue for the future of human conflict and the well being of those involved in, and the environments affected by, such conflicts.

THE RAND REPORT

This independent report concludes that no negative health effects resulting from radiation from DU or natural uranium have been observed in humans but presents no evidence to support this conclusion. No studies on DU exposure in the Gulf War have been undertaken or commissioned. Cancers rates would not be expected to rise markedly until ~10-20 years after the conflict. This is a classic case of denial without investigation. It is yet another example of bad science, spurious conclusions, and "tin ears, cold heart and closed minds" associated with the many questions surrounding the Gulf War.

RESPONSE TO QUESTIONS

Qu. Is there any way in which battlefields can be cleaned-up?

Ans. No. The cost is just too high. The Jefferson Proving Ground where 69 tons of DU had been fired along with other ammunition was estimated to cost $4-5 billion dollars to clean-up. The result of any clean-up would still require the storage of contaminated sludges/earth which contained the low level nuclear waste. DU will not go away.

The USA gave no undertaking to clean-up the Gulf battlefields. Saudi, Iraq, Kuwait, and Bosnia, Serbia, Kosovo are stuck with the problem.

Qu. Can any treatment be given to the Gulf Veterans and Iraq soldiers and civilians?

Ans. The most effective treatment has to be given as soon as possible after exposure and works best with soluble uranium compounds. The increased removal of insoluble/ceramic uranium compounds will, at best, be very slow or not possible. Some programmes of detoxification offer some hope of some treatment. This is an area where much more study is needed. At the present time a variety of natural and synthetic chelating agents have been used. Distilled water or sodium bicarbonate solution have also proved useful to a degree.

I am afraid that for many Veterans the damage has already been done. In adults the increased numbers of cancers will only become apparent some 10 or more years later. The health of Veterans must be carefully monitored and treatment given immediately when malignant or pre-malignant condition is identified.

Qu. The Gulf Veterans were exposed to other hazards-what contribution did these make to the illnesses they are experiencing?

Ans. There were six major chemical and biological insults that the Gulf Veterans experienced.

1. The rushed and extensive vaccination programmes which included novel, untried, vaccines.
2. The use of Pyridostigmine Bromide as an untried prophylactic medicine in case of exposure to nerve agents.
3. The extensive use of many different insecticides including, particularly, the organophosphates and lindane -much of this was originally denied by the UK Government.
4. Exposure to crude oil and smoke from the oil well fires.
5. Exposure to DU dust from the use of DU ammunition.
6. Low level exposure to nerve agents and sulphur mustard gases, originally denied by the USA Government and still denied by the UK Government, and possibly biological agents for which there were no means of detection on the battlefield.

The difficulty is deciding which of these insults played the major part in Gulf War illnesses. There are good reasons to think that for some the vaccines provoked a major dysfunction of the immune system, for others pyridostigmine could have played a significant role- the recent Rand Report supports this. DU exposure could certainly be a major factor, and little attention has been paid to the potent irritants and carcinogens in crude oil and the smoke from the oil wells.

This is why Bosnia and Kosovo are so important. Exposure to DU in these locations will not be overlaid with vaccine damage, excessive insecticide use, or exposure to chemical and biological weapons.

CONCLUSIONS AND RECOMMENDATIONS

1. **We now know enough about the consequences of the use of DU munitions in the Gulf War to realise that these weapons are indiscriminate, unpredictable and affect friend and foe, civilian and military and unborn generations and the whole environment alike.**
2. **It is important to examine EVERY Gulf War Veteran for possible contamination by DU. This will provide information essential to the health care of the Veterans.**
3. **Similar examinations should be made of Iraqi military personnel, civilians, in and around the battlefields and target areas.**
4. **This data will provide information about the spread of DU dust and contamination of people and environment.**
5. **The quantities and types of DU ammunition used and targets hit in Bosnia, Serbia, and Kosovo should be declared.**
6. **People, livestock, soil, water supply, plants and animals from all the affected areas should be examined.**

THE MANUFACTURE, TESTING, AND SALE OF DU MUNITIONS SHOULD STOP IMMEDIATELY.

THOSE COUNTRIES POSSESSING DU MUNITIONS SHOULD AGREE NOT TO USE THEM IN ANY CONFLICT. AND DESTROY THEIR STOCKPILES.

DU WEAPONS SHOULD BE BANNED BY INTERNATIONAL AGREEMENT SINCE THEY ARE INDISCRIMINATE WEAPONS WHICH AFFECT COMBATANTS, NON-COMBATANTS AND FUTURE GENERATIONS ALIKE.

WAR CANNOT BE WAGED WITH THESE WEAPONS. SOME OTHER WAY OF RESOLVING HUMAN CONFLICTS MUST BE FOUND.

ACKNOWLEDGEMENTS
I am particularly grateful to Rosalie Bertell and Hari Sharma for their generous and expert help in preparing this lecture and for sharing their own insights and information about DU. Pat Horan's important work was made known to me through Shaun Rusling of the National Gulf Veterans and Families Association. Asaf Durakovic has shared much of his concern about the use of DU and its clinical effects. Dan Fahey of Swords and Ploughshares provided a massive collection of data and references drawn from military and other sources. Larry Cammock and Tony Duff of the Gulf Veterans' Association first got me involved with Gulf War Illness. Their friendship, stories and support have encouraged, edified and stimulated me.

SOURCES OF INFORMATION
There are many sites on the internet where excellent information is available
Professor Leonard A Dietz and Military Toxics Project
http://antenna.nl/wise-database/uranium/dmtp.html This site has many contributions from a variety of authoritative sources

Dan Fahey. Case Narrative: Depleted Uranium (DU) Exposures, 1998. Available at National Gulf War Resource Center, Inc. 1224 M St, NW Washington, DC 20005, USA. http://www.gulfweb.org/ngwrc
This is a comprehensive documentation of the sources of the information on DU. It is particularly useful for its references to Military studies which have not been reported in the published literature.

Vladimir S Zajic
http://www.members.tripod.com/vzajic/vzajic.html This is a new site which provides much detail and many references about the scientific aspects of radiation and DU. I am indebted to Dr Zajic for much of the most of the pictures and the cartoon used in this lecture.

http://raleigh.dis.anl.gov/roadmap/achre/intro_9_7.html This valuable site contains much useful information about the often confusing nomenclature in radiation physics, chemistry and biology.

LAKA Foundation, the Netherlands Documentation and Research Centre for Nuclear Energy. This publication brings together the work of experts in various aspects of DU. It is essential reading.
E-mail laka@laka.antenna.nl

Rosalie Bertell, President ACS, Toronto, Canada
Gulf War Veterans and Depleted Uranium- Address to the Hague Peace Conference, May 1999. Rosalie has been involved with the DU issue from the beginning. She is as world authority.

Hari Sharma like Rosalie Bertell, is a world expert. He has been involved from the beginning and carried out most of the initial analytical work which laid the foundation for our present understanding of the DU question.

WISE WORDS

Roots of Conflict-"Never think that wars are irrational catastrophes; they happen when wrong ways of thinking and living bring about intolerable situations" Dorothy L Sayers: 'Creed or Chaos'.

"In the search for a reasonable world view, we should turn in the first place to common sense".
Michael Polanyi

ABOUT THE AUTHOR
He obtained his degrees from the Faculty of Medicine, University of London, B.Pharm. (1956), Ph.D. (1959). and subsequently the C.Chem. MRIC of the Royal Society of Chemistry in 1963.
1959: Appointed Lecturer in Pharmaceutical and Medicinal Chemistry, School of Pharmacy, Sunderland Technical College finally rising to Professor of Medicinal Chemistry in the new University of Sunderland from which he retired in August 1993 when he was honored with the title of Emeritus Professor of Medicinal Chemistry.
He has had a long career in teaching and research covering Honours Degrees in pharmacy, pharmacology, and pharmaceutical and chemical analysis. He directed research at Masters and particularly Doctoral level; supervising some 21 Ph. D. students in all.
Some 50 papers have been published in peer reviewed journals in the field of medicinal chemistry together with major reviews on the Chemotherapy of Leprosy, and, the Chemistry of Isatogens. He has edited one book on the Chemotherapy of Tropical Diseases.
He has acted as a referee for a number of important journals and served on one editorial board as well as on Committees of the Council for National Academic Awards, World Health Organisation, Science and Engineering Research Council.
He is a member of a number of learned societies including the Royal Chemical Society, the British Pharmacological Society, the Society for Drug Research, SDR, (now renamed as the Society for Medicines Research) of which he was Chairman for 2 years.
In June of 1997 he met four Gulf War Veterans who visited the Autism Research Unit at the University of Sunderland and was invited to be Chief Scientific Advisor to the Gulf Veterans Association, GVA. He is a member of, the Independent Panel established by the UK Government to assess research into the possible interaction between vaccines and NAPS (pyridostigmine bromide tablets), and the Gulf Support Group run by the Royal British Legion. Increasingly, he has developed an interest Chronic Fatigue Syndrome/Myalgic Encephalomyelitis, CFS/ME, and related disorders which are allied to Gulf War illnesses in many ways.