

Occupational Hazards of War

**DEPLETED URANIUM: ALL THE QUESTIONS ABOUT DU AND GULF WAR SYNDROME ARE NOT YET ANSWERED**

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For 15 years, the debate about depleted uranium (DU) and its detrimental effects on the health of veterans of the Gulf War of 1991, on the Iraqi people and military (and subsequently on the people of Kosovo, Afghanistan, and Iraq during the second war) has remained unresolved. Meanwhile, the number of Gulf War veterans who have developed the so-called Gulf War syndrome has risen to about one-third of the 800,000 U.S. forces deployed, and unknown proportions of those involved in the subsequent wars. Uncounted civilians and personnel of other nations that fought in Iraq and other wars since 1991 have also been afflicted. The veterans have suffered from multiple serious physiological disorders and have received little or no official recognition, medical relief, or compensation. We need to take another look at this issue, using a holistic and interactive model for the toxic matrix of exposures, identifying the major roadblocks to resolving the scientific questions, and finding appropriate medical and political responses. This commentary is such an attempt.

THE PROBLEM

One of the novel exposures of the Gulf War of 1991 was the depleted uranium (DU) missiles, rockets, and armament. Uranium is a radioactive heavy metal, one that has no positive biological use. Exposure to DU during the Gulf War occurred along with exposure to other heavy metals well known to cause havoc with the cellular immune system. “Depleted uranium” is an industry term for uranium waste from the enrichment of uranium ore, which concentrates the isotope uranium-235 for use in nuclear bombs or nuclear power reactors. It makes up the largest amount of radioactive waste globally, related to the nuclear industry (excluding mining waste). In the United States, DU must be handled by persons trained in radiation safety and must be isolated from the biosphere according to strict regulations

Uranium-238 (U-238) is an alpha emitter with rare spontaneous fission. The alpha half-life of U-238 is 4.5 billion ( $4.5 \times 10^9$ ) years. It decays to thorium-234 (Th-234), which has a half-life of 24.1 days and is a beta and gamma emitter. Thorium-234 decays to protactinium-234m (Pa-234m), an isomer of Pa-234, which has a half-life of 1.17 minutes and is an alpha emitter. Protactinium-234m decays to Pa-234, which has a half-life of 6.7 hours and is an alpha emitter. Effectively, in four to six months after it is discarded from the enrichment facility, freshly produced DU, composed mostly of U-238, through these continuous radioactive transformations becomes a mixture of U-238, Th-234, Pa-234m, Pa-234, and U-234 in equilibrium proportions. The first two decay products, Th and Pa, along with U-238 account for most of the alpha, beta, and small amount of gamma radioactivity of the mixture (1, p. 11).

With air friction or impact on a hardened target, uranium bursts into flame. The temperature of this spontaneous metal fume produced by DU is between 3000°C and 6000°C. This is in contrast to an Iraqi ambient temperature of 22°C to 45°C or the 575°C fire produced by TNT in other wars. At this high temperature the uranium oxide becomes ceramic-like, and insoluble in body fluids (2). For this reason, once inhaled, it provides a chronic source of uranium heavy metal and contact radiation poisoning within the body.

Other heavy metals, in addition to DU, especially mercury, lead, arsenic, and cadmium, were used extensively in the Gulf War. They were contained in pesticides and herbicides; in vaccines, including anthrax and botulinum toxin; in nerve agents: sarin, cyclosarin, tabun, soman, VX, multiple seven, and novachuks (novichoks); and in chemicals released from the Kamasiyah toxic chemical depot, which was destroyed by bombing. Many veterans were also subjected to petroleum products and the horrendous oil well fires (3). Most had very little training for handling these hazardous materials, and no protective clothing or respirators.

One focus of the dispute about Gulf War syndrome (GWS) has been whether or not the use in battle of DU weaponry could be one of the principal causes of the disabling syndrome. The first roadblock to clarifying this scientific hypothesis results from focusing on only one item at a time to which veterans were exposed in battle and attempting to “prove” that it was or was not one of the main causes of their serious illness. One could attempt to do this for each pesticide, vaccine, toxic chemical, and heavy metal separately, pretending to “prove” for each that it was not the cause. Such reductionist discourse confuses the true issues and delays research into treatment and legal recognition of harm caused. It leads one to the absurd conclusion that the veterans are not really sick—that the problems are all in their imagination.

Influential papers by physicists and several semi-official governmental organizations have attempted to eliminate DU from consideration by just such analyses (4–8). These studies are not really independent, since each follows the guidelines, methodology, and risk estimates recommended by the International Commission on Radiological Protection (ICRP) (9).

Since the U.S. Research Advisory Committee on Gulf War Veterans’ Illnesses has ruled out psychiatric illness as a cause of GWS (3), it is important to look again, at all the circumstances associated with the use of DU, including uranium’s heavy metal as well as radiological properties, and their combined effects on the immune, neurological, hormonal, and reproductive systems of exposed veterans and civilians. A damaged immune system leaves one vulnerable to all sorts of viral, bacterial, electromagnetic, radiological, and toxic metal exposures. The hormonal system regulates homeostasis, the nocturnal resting cycle (for repair), and kidney clearance rates of heavy metals. When evaluating DU use in war, we must do so within this total toxic matrix.

## ANALYZING THE RADIOLOGICAL HAZARD

Uranium-238 is radioactive, an alpha emitter with rare spontaneous fission. As noted above, freshly produced DU, composed mostly of U-238, becomes a mixture of U-238, Th-234, Pa-234m, Pa-234 and U-234 within about six months. The first two decay products, Th and Pa, along with U-238 account for most of the alpha, beta, and small amount of gamma radioactivity of the mixture. One milligram ( $1 \times 10^{-3}$  gram) of pure U-238 undergoes 12.4 atomic transformations (submicroscopic explosions) every second, each giving off one alpha particle with energy between 4.15 and 4.2 MeV (million electron volts) in random directions. It only requires 6 to 10 eV (electron volts) to break the nuclear DNA strand in a cell. In one day, 1 milligram of pure U-238 would release 1,071,000 alpha particles, each with more than 4 MeV of energy, into the organ or tissue where it was lodged. The spherical range of these alpha particles is about six cells. The radioactivity emitted by the mixture of uranium and its decay products is even greater.

The spontaneous fission half-life for U-238 is estimated to be  $8.5 \times 10^{17}$  years, which, although much longer than its alpha decay half-life, results in approximately two atoms of U-238 in every milligram of uranium decaying by this process each year. When it decays by spontaneous fission, U-238 releases approximately 40 times more energy than in nuclear decay (1, p. 6).

The widely accepted scientific causality methodology for analyzing radiation dose-response includes a mathematical model predicting damage to the cellular DNA resulting from a homogeneous spread of ionizing radiation over the critical organ(s), weighting the organ dose to approximate whole-body exposure, and using a risk formula to estimate the expected number of fatal cancers due to that dose. If the calculation yields only a small expected number of cancer deaths, the radiological hazard is declared to be trivial. This ICRP methodology assumes that the affected persons care only about cancer death, that they have normal physiological health and intact cellular repair systems, and that no other life-threatening exposures confound the radiation experience. The methodology assumes that radiation effects are independent of the effects of the toxic matrix and can be separately ruled out using a radiation-exposure-specific mathematical formula recommended by physicists on the main committee of the ICRP.

Whether an assumption of homogeneous spread of the energy over the organ in question is reasonable under the circumstances, whether the estimates of the amount of radiation inhaled are accurate in the confusion of the battlefield, whether the cellular repair system is working, whether the clearance rate for heavy metals by the kidneys is normal, or even whether cancer is meaningful as the biological endpoint of concern for veterans—all makes no difference. These details seem to be irrelevant when applying this “objective” methodology. In this report I will show that this trusted methodology is especially inappropriate and misleading in the case of Gulf War syndrome. The mathematical equation contains no terms for dealing with cellular repair dysfunction, damage to mitochondrial DNA, and synergistic effects with a variety of toxic metals, halogens, and complex nano-debris. Inhalation of airborne nano-debris is especially difficult to measure, since this debris can theoretically remain in the air forever by Brownian motion, or can suffer multiple resuspension events if it does fall to the ground. In war, the build-up of this airborne debris is cumulative.

## ORIGIN AND LIMITATIONS OF THE PHYSICS METHODOLOGY

In 1945, the physicist Erwin Schrödinger published what became one of the most influential monographs of the incipient atomic age. In *What Is Life* (10) Schrödinger gave the central and primary informational role in life to the nuclear DNA. He found it to be the basis of all organic existence, and he explained it well in terms of fundamental physical and quantum principles. This was a brilliant thesis, and it was followed in 1953 by Watson and Crick's discovery of the method of DNA replication. DNA was spectacular news in the scientific world at this time. However, nuclear DNA, while central to protein production and human reproduction, failed to describe the many seemingly unrelated life-support mechanisms, including the tasks of mitochondrial DNA, which also go into making the cell functional.

The developing science of radiobiology accepted the thesis that nuclear DNA was the essential molecule of radiosensitivity, and this focus continues to strongly influence decisions about the potential hazard of exposures to ionizing radiation, even in 2006, as nations are called upon to deal with the complex Gulf War syndrome. We now know that cellular organelles, cell membranes, and biochemical reactions within the cell are crucial when assessing the simultaneous damage caused by internal radiation, heavy metal contamination, and nano-particles. The radiation dose-response methodology, developed from studies of high-dose-level radiation, seems to work by masking the low-dose effects. It is not appropriate for understanding low-dose DU exposures, because radiation, heavy metals, and other toxic chemicals can destroy the functionality of the cellular respiratory system, (including the mitochondria), disrupt the chemistry of enzymes and hormones, frustrate normal cellular detoxification and repair, and leave the person alive but chronically ill.

Also at low doses, many other toxic agents become potentially synergistic or significant confounding variables for any radiation toxic effect. As I will show, a system approach is more fruitful, and for the individual, the two most important systems to examine are the cellular immune system and hormonal system. Critical for civilization and survival is human reproductive health.

The ionizing radiation exposure in the first Gulf War included, in addition to DU, exposure to nuclear debris caused by the bombing of the Iraqi experimental nuclear reactors and spent fuel pools, and radiation from the Doha explosions and six-day fire that consumed DU ordnance stored at the U.S. military depot near the border with Kuwait. No one single radiation dose would comprise all these many levels of radiation exposure experienced by military and civilian personnel. These various exposures would be cumulative.

## TOXIC CHEMICAL AND RADIOLOGICAL DAMAGE TO CELLS

Depleted uranium powder is pyrophoric, and spontaneously creates an invisible metal fume (often called an aerosol) when exposed to air friction or impact on a hardened

target. The nano-particles created in the metal fume, when inhaled, can cross the lung-blood barrier, penetrate cells, and provide the maximum dose to tissue (contact dose from a maximized surface area-to-volume particle, with little self-shielding), creating free radicals and oxidative stress within cells. Some scientists believe that the oxidative stress caused by uranium's heavy metal properties is even more damaging than its radiological properties. Total oxidative stress causes failure of protective enzymes, leaving cells vulnerable to viruses and mycoplasmas. Damage to the cellular communication system and the mitochondria; heavy metal replacement of magnesium in molecules that normally function as antioxidants; and destruction of the body's repair mechanisms, have serious consequences including chronic disease and tumorogenesis. Some cellular mechanisms are of special interest here. For example, after a protein, sequenced by the DNA, is properly synthesized by the RNA, it has to undergo a process of folding. This gives it the proper three-dimensional shape to carry out its functions and chemical reactions. Biochemists now believe that proteins do not fold spontaneously into their final, active conformation (11).

Proteins destined to be embedded in the cell membrane or to be secreted from the cell are synthesized in the endoplasmic reticulum, where templates, enzymes, and sugars promote some protein conformations and inhibit others. This is delicate work with sequential rounds of intricate modifications, overseen by the cell's quality-control system. Free radicals can totally disrupt this process, forming unusual molecules; and in the presence of heavy metals, the process may use trace amounts of toxic metals to replace the normally used zinc and manganese. Improperly folded proteins can fail to be routed to the cell membrane or to a gland where, as hormones, they are needed to release biochemical signal molecules.

Some diseases caused by misrouted proteins include cystic fibrosis, diabetes insipidus, and cancer (12). Widespread misfolding of proteins can lead to cellular stress, clogging of the system, and an accumulation of imperfect proteins. Many scientists now believe that accumulation and aggregation of misfolded proteins is responsible for neurodegenerative diseases, as well as early-onset Alzheimer's disease, Parkinson's disease, and diabetes mellitus. In these diseases, proteins or protein fragments convert from normal, soluble conformations to insoluble, sticky fibers called amyloids.

Amyloids coalesce into fibrillar aggregates that have a characteristic structure. The insoluble clumps can form either inside or outside cells. Misfolded proteins are a central pathogenic mechanism, and Gulf War veterans have manifested many of the symptoms of these neurodegenerative diseases.

## THE PROBLEM OF AMYOTROPHIC LATERAL SCLEROSIS

Amyotrophic lateral sclerosis (ALS; commonly known as Lou Gehrig's disease) is being diagnosed at about twice the expected rate in young Gulf War veterans relative to veterans who did not serve in the first Gulf War (confirmed in September 2004 by the U.S. Research Advisory Committee on Gulf War Veterans' Illnesses). Normally, ALS is diagnosed after the age of 55 years, but most of these Gulf War veteran patients are

younger. In two-thirds of the 40 cases, the patients are between 20 and 54 years old. ALS is officially listed as “of unknown cause.” However, it seems clearly related to the failure of anti-inflammatory and antioxidant enzymes, together with mitochondrial dysfunction. ALS was thought to be caused by the death of motor neurons. Recent data suggest, however, that neurons do not so much die as they are killed by surrounding cells called glia. The glia usually support and nourish neurons, but they can become dysfunctional and toxic in certain diseases. This process is called “neuro-inflammation.”

Cytokines are small proteins that communicate between neurons and glia cell types (13). The cytokine signaling is, in turn, regulated by major lipid metabolic pathways. Recent data suggest that neuro-inflammation in a mouse model of ALS is caused by dysregulated cytokine signaling. Michael Vickers (14) has documented that even microgray doses of ionizing radiation cause inflammation of the blood vessels and can initiate the arachidonic cascade, with its well-known sequel of damaging effects on the body. Arachidonic acid is the lipid produced when fatty acids in various states of oxidation mediate inflammatory reactions in the blood and other cells. This certainly merits further study, since ALS is a very serious and unexpected outcome for these Gulf War veterans.

An unusually high incidence of ALS and Parkinson’s disease in indigenous populations in Guam and Papua New Guinea suggests a possible correlation between the diseases and local environmental conditions, including high levels of aluminum and low levels of calcium and magnesium in soil and food. As in Alzheimer’s, humans with these disorders tend to have high levels of aluminum in some areas of the brain, although it has not been demonstrated that the presence of aluminum in the brain initiates the onset of the diseases. It has been suggested that other possible contributing factors need to be examined more closely, including the diet of the Guam population—in particular, the seeds of the false sago palm, which contain a toxic amino acid that causes a condition similar to ALS in monkeys—as well as the possibility that the disease is caused by genetic rather than environmental factors (15). Both potential factors—the false sago palm and genetic factors—seem to be absent in the Gulf War cases, but exposure to aluminum and depletion of calcium and magnesium were present. Guam and Papua New Guinea likely received some fallout from U.S. and U.K. nuclear bomb tests in the Australian and Pacific areas, which may have introduced unexamined internal radiation exposure factors that would clarify this mystery.

## IMMUNE AND HORMONAL SYSTEMS DAMAGED IN THE GULF WAR

The DNA of mitochondria is 16 times more sensitive to radiation than is nuclear DNA. This is because mitochondrial DNA has no protective histone proteins, like those within the cell nucleus (16). It is well known and well accepted in the scientific community that ionizing radiation produces free radicals (molecules with one or more unpaired electrons) in living cells, which are composed mostly of water. It does this because of its ionizing energy deposit, which knocks an electron out of orbit, creating a positively charged atom or molecule with at least one unpaired electron (a positive ion) and a free electron (a negative ion). Because another molecule can easily pick up the free electron, causing a chemical reaction, free radicals can effect dramatic and destructive changes in the cell

and in the intercellular fluid. Karl Z. Morgan, the renowned health physicist, described this effect as “a mad man in a library.”

All cells contain an endogenous antioxidant in the water-soluble part of the cellular fluid, which normally deals with free radicals. This antioxidant, called glutathione (GSH), repairs most cellular structures that are damaged and oxidized by free radicals. It can also detoxify many electrophilic mutagenic threats to the cell. This antioxidant function of GSH is normally credited as having cancer-protective properties, since it neutralizes free radicals. Cellular repair mechanisms depend heavily on the presence of GSH in cells.

Another function of GSH is to rid cells of toxic heavy metals. Heavy metals bind with the GSH and are carried out of the cell and to the gallbladder, for excretion in bile. This process is a mechanism for depleting the GSH, as well as for ridding the cells of heavy metals. Hence heavy metals, such as DU, deplete GSH at the time when it is most needed for its protective cell-repair and antioxidant work. Individuals may have more or less GSH by nature or through exposure history. Yet this is one of the main biochemicals needed for the repair mechanisms on which the physics methodology for calculating radiation dose-response depends for its applicability.

Superoxide dismutase (SOD) is another chemical, an enzyme produced both by the liver and in the mitochondria of all cells, which acts as an anti-inflammatory and antioxidant. The body needs zinc, copper, and manganese to produce sufficient functional SOD. Toxic metals can replace the manganese, making the SOD dysfunctional, or the cell can merely run out of SOD because of overdemand for antioxidants in the mitochondria. This overdemand can also deplete the manganese needed for protective enzymes in the cell, leaving it open to viral or bacterial invasion. SOD also varies in abundance and can be damaged by a variety of chemicals. Mercury and arsenic are found in pesticides and fungicides, and in vaccines. Nickel is a component of steel, which can be vaporized in a DU metal fume. Nickel can deplete the body's zinc stores, compromising the SOD cellular immune system. These other metals also play parts in the breakdown of cellular functions. Thus heavy metal exposure causes oxidative stress that weakens the cellular repair mechanism, which would normally provide some protection against low-dose radiation exposure from DU.

### *Disturbance of Thyroid Function*

Trace amounts of inhaled or ingested aluminum from inoculations, aluminum food wrappings, cooking utensils, salt, baking powder, beer, soft drink cans, or other sources could combine with fluorides from hydrogen fluoride released from oil well fires, fluoridated drinking water, soft drinks, toothpaste, or foods (made with fluoridated U.S. water) to form a pseudo-hormone that mimics the thyroid-stimulating hormone (TSH)—even confusing medical tests for thyroid dysfunction. Hormonal damage to the thyroid and pituitary glands, which regulate metabolism, has severe repercussions for every organ system in the body, including the brain. Aluminum fluoride compounds act like TSH, which regulates the thyroid hormones T-3 and T-4. When persons are subject to trace aluminum and fluoride, they exhibit the same symptoms as in hyperthyroidism. This

pseudo-TSH bypasses the pituitary control of cell metabolism, drives up mitochondrial activity, and depletes the selenium-GSH in all cells (17).

Aluminum fluoride compounds provide another mechanism that interferes with cellular repair of radiation damage due to DU. The aluminum fluoride compounds do not clear from the body as does TSH. The highly electronegative effects of the fluorides cause long-term (almost permanent) bonding to the TSH receptor sites of cells. This process greatly disturbs the normal pulse and amplitude processes of pituitary control by TSH and damages the cellular nocturnal repair processes, overworking the GSH in cells. Authentic TSH provides for the normal sleep cycle, which helps the body recover from toxic shock. Sleep deprivation can lead to many functional problems.

Aluminum fluoride complexes have been widely used in laboratory investigations for stimulation of various guanine nucleotide-binding proteins (called G-proteins). These complexes can simulate phosphate groups in many biochemical reactions. It is evident that an aluminum fluoride complex gives false information, which is then amplified by cellular processes of signal transmission, influencing the G-proteins that carry signals from numerous receptors to the cell interior (18). Serious aluminum fluoride problems have been reported at the St. Regis Akwesasne Indian Reserve on Cornwall Island, New York State, downwind from the Reynolds Metal Company aluminum smelter.

At Oak Ridge, the U.S. Department of Energy nuclear weapons facility, illnesses similar to GWS are increasingly encountered. These illnesses have not been diagnosed and many go untreated. Aluminum and hydrofluoric acid, as well as DU waste, are part of the pollution of this and other Department of Energy facilities. Victims of the environmental disasters at the weapons facilities report muscular and skeletal problems, nervous system disorders, anemia, rashes, irritability, high blood pressure, and thyroid problems (19, 20).

Heavy metal exposure (including uranium) can cause loss of cellular immunity, autoimmune diseases, joint diseases such as rheumatoid arthritis, and diseases of the kidneys, circulatory system, and nervous system. Heavy metals supplant the normal calcium and other minerals in enzymes, and cause these molecules to lose their important functions in the body. Peroxynitrite, a toxic product of the free radicals nitric oxide and superoxide, can also degrade the functions of respiratory enzymes (21) and inactivate the manganese-SOD enzyme (22). Decline in functional mitochondria is most damaging to those organs that have the highest energy demands per gram of tissue—namely, the heart, kidney, brain, liver, and skeletal muscle, in that order (16, 23). These organs become poorly protected against irradiation from circulating uranium particles, as well as various other pathogens.

#### *Mycoplasmal Invasion Related to Depleted Uranium Exposure*

Failure of cellular immunity leaves an organism vulnerable to viral, bacterial, and mycoplasmal invasion. Mycoplasmas are small bacterial organisms. Lacking cell walls, they are capable of invading several types of human cells and are associated with a wide variety of human diseases.



Several separate laboratories in the United States (e.g., Dr. See at the University of California, Irvine, and Dr. Lesko of Del Mar, California) have identified mycoplasmal organisms in patients with chronic fatigue syndrome and Gulf War syndrome. The percentage of positive findings for mycoplasma ranged from 60 to 80 percent of patients examined. Research by Drs. Garth and Nancy Nicolson of the University of Texas M.D. Anderson Cancer Center resulted in the discovery of *Mycoplasma incognitus* as one cause of the symptoms of GWS. Their daughter had returned from the Gulf with the syndrome. Normal laboratory blood tests do not detect *M. incognitus*. The only way to detect this mycoplasma is to use a sensitive genetic marker analysis. Even with this method it is difficult to detect, because unlike conventional bacteria, the mycoplasma is found mainly inside cells and not in body fluids (24). *Mycoplasma incognitus* causes chronic fatigue, recurring fever, night sweats, joint pain, stomach upsets, stomach cramps, headaches, skin rashes, heart pain, kidney pain, thyroid problems, and, in extreme cases, autoimmune-like disorders.

Certainly there was nothing normal about the metabolic responses of Gulf War veterans to the radiation injuries from DU. While it is credible that uranium was not responsible for all the sickness experienced by the veterans, it clearly was not as minimal a component as would be indicated by the mathematical approach used in physics. The mathematical approach cannot predict what DU exposure would cause in this situation, since the chemical and biological reactions are interdependent and find no accommodation in the mathematical formula.

#### DEPLETED URANIUM IN BATTLE VERSUS URANIUM OXIDE IN MINES OR MILLS

Uranium oxide, as found in uranium mining and milling, has provided much of the information used for the official understanding and evaluation of exposures to DU in the first Gulf War (5). DU exposure in war differs, however, in that uranium oxide in the mining and milling situation is dust—visible particles of, on average, 5 microns aerodynamic diameter. Some of the inhaled uranium in war will be similar to this mine dust, but the aerosolized uranium oxide from a metal fume, produced through air friction or impact on a hardened target, is invisible, with an aerodynamic diameter between 1 nanometer and 2.5 microns. Size is an important factor for inhalation. Particles with an aerodynamic diameter less than 2.5 microns can penetrate into the deep lung alveoli. When the aerodynamic diameters are in the nanometer range, particles easily penetrate the lung-blood barrier and are carried throughout the body. The aerosolized molecule may well be a crystal with a different number of oxygen atoms than the uranium oxide in mines.

Another difference between the two situations is that mine uranium is contaminated with radium and radon, whereas these have been virtually eliminated in DU. Mine dust is produced at ambient temperatures, while the metal fume is produced at temperatures between 3000°C and 6000°C. Subjecting uranium oxide to more than 3000°C produces what the U.K. National Radiation Protection Board (NRPB) refers to as ceramic uranium

oxide, which is highly insoluble in body fluids (2). These high temperatures also sublimate all other metals and materials that happen to be nearby, caught in the powdered uranium fire: steel, nickel, aluminum, iron, and so forth. This other debris will also aerosolize and produce nanometer-size debris, which can be inhaled (25).

The small size of these particles facilitates uptake into cells and transit across epithelial and endothelial cells into the blood and lymph circulation, thus reaching potentially sensitive targets. These targets include lymph nodes, spleen, and heart. Access to the central nervous system and ganglia via translocation among axons and dendrites of neurons has also been observed. The greater surface area per volume, compared with larger particles, renders nano-particles more biologically active.

Uranium miners must assume simultaneous exposure to radium and radon, while DU used in battle eliminates these exposures but involves a complex toxic matrix of other exposures. The differences in health effects in the receptor or host in the mining versus the battlefield environment are major.

#### HUMAN ABILITY TO SCREEN OUT URANIUM

The human body is normally exposed to uranium in food and water at a rate of about 1.9 micrograms a day, but only about 1 to 2 percent— between 0.019 and 0.038 micrograms (19 to 38 nanograms)—is absorbed through the intestines. The output of natural uranium in feces is 1.862 to 1.881 micrograms daily. Physiologists consider the entire gastrointestinal tract to be external to the body (like the hole in a donut), so this fraction of ingested uranium in water and food is not considered internal contamination. The 19 to 38 nanograms of natural uranium that is absorbed through the intestinal wall is considered to be internal to the body. It passes through the hepatic portal system and is screened by the liver, then either sent directly to the kidneys to be excreted in urine or circulated in the blood. Circulating uranium is usually stored in bone, to be excreted at a later time. These outcomes vary according to the solubility of the uranium compounds in food and water. However, these estimates are typical for natural uranium. The human body has an excellent screening system for natural uranium reducing the ambient average environmental concentration of 1 part per million to less than 38 parts per billion internally.

However, this gastrointestinal and liver screening system does not operate to screen out the uranium or other metals that enter the body through the lungs, are ceramic, and have an aerodynamic diameter in the nanometer range. Gulf War exposures to inhaled DU were likely well above the normal 19 to 38 nanograms per day and added considerable stress to the body, regardless of the other stresses present in this toxic war. Nano-particles (whether uranium, steel, iron, or aluminum) pose an especially difficult problem for the body's screening and filtering ability. They pass through the lung-blood barrier, the blood-brain barrier, and the placenta, and they are too small to be filtered out by the kidneys and excreted from the body (26). They take a long time to dissolve in the body fluid, and only the dissolved portion can be chemically active or eliminated in urine. Because of the variable times needed for dissolving the ceramic forms, the negative effect

of the radioactive heavy metal is ongoing. Ceramic uranium may never dissolve, and it does not lose its radioactive properties.

## CARCINOGENIC PROPERTIES OF URANIUM

While the neurological, immunological, and reproductive damage are the first problems to surface for veterans and civilians exposed to DU, the long-term effect of greatest concern, other than intergenerational genetic deterioration, is likely to be cancer. Note also that early cancers, which have at times been attributed to DU, are most likely secondary to the immunological effect. A depressed immune system often changes the status of a sub-clinical cancer, with which the individual is coping, into a clinically diagnosable cancer. There is no doubt about the ability of radiation to initiate cancer and also to promote cancers initiated by other carcinogens. The work of Peter Nowell (27) has recently been extended by research into radiation-induced genomic instability. According to W. F. Morgan and colleagues: "The loss of stability of the genome is becoming accepted as one of the most important aspects of carcinogenesis" (28).

The Armed Forces Radiobiological Research Institute has now admitted that DU can cause cancer (29). Miller and colleagues have also found that tiny amounts of DU, too small to be toxic and only mildly radioactive, cause more cytogenetic damage in cells than either the toxicity or radiation alone could explain. Their latest results (30) corroborate a tentative report by the Royal Society (7), which suggests that the toxicity and radioactivity of DU reinforce one another in an unknown way, to the extent that more than eight times as many cells suffer cytogenetic damage than predicted. Thus the carcinogenic and genotoxic health risk of DU could be grossly underestimated by current theories.

There is also serious discussion among radiobiologists about the inadequacy of the ICRP model for dose and dose-response, based on the physics model. There is growing agreement that this model is inappropriate for application to internal alpha emitters (31). Both NATO (32) and the Institut de Radioprotection et de Sûreté Nucléaire (33), the official French radiation protection organization, have found the ICRP methodology to be faulty. The question of DU carcinogenicity is actually much larger than the questions raised by Gulf War syndrome; it involves the actual cause of the excess cancers at Hiroshima, Nagasaki, and Chernobyl, where burning uranium fuel particulates may have played a much larger part in the observed cancers than atomic bomb or International Atom Energy Agency research has projected. Since no internal dose estimates were ever attempted at Hiroshima and Nagasaki (34), and the dose estimates around Chernobyl were focused on cesium-137 and iodine-131 (35), the effect of uranium and plutonium fuel aerosol was neglected. By assuming that the DU in war would act like uranium dust in mines, the experts made the mistake of assuming that the signature of this exposure would be uranium storage in bone and damage to the kidney tubules. Because these effects were not dominant—though they did occur—DU was dismissed as a cause of GWS. With what is now known about the physical form of the DU, with the complication of ceramic nanoparticle formation, this was not a realistic assumption.

The cancers may be expected to appear over the next 20 to 50 years. The latency period will probably be longer than expected for these cancers because of the chronic low-dose effect. Moreover, many Gulf War veterans will die before expression of the cancers, because of competing causes of death.

## TERATOGENIC TOXICITY

Soluble uranium oxide and all nano-particles can cross the placenta, and these are particularly toxic to the rapidly developing embryo or fetus. At low doses, they damage the fetal brain, causing behavioral problems, such as aggressiveness and hyperactivity, and mental retardation. Other teratogenic effects are congenital malformations and diseases. The underdeveloped immune and hormonal systems of the fetus are more easily compromised than in a fully mature adult.

One official epidemiological study did look at the health of the offspring of Gulf War veterans. This was a study of veterans in general and was not limited to those either with GWS or with known exposure to DU. This study of birth defects in the children of veterans in the United States, undertaken by Han Kang of the U.S. Department of Veterans Affairs (36), focused on the first pregnancy after returning home from the Gulf War. Slightly less than 21,000 veterans, from all four branches, active and retired, were included in the study (about 70% of those to whom questionnaires were sent). Male Gulf War veterans were twice as likely, and female veterans almost three times as likely, to report children with birth defects than their counterparts who did not serve in the first Gulf War. Birth defects included webbed fingers and toes, heart murmurs, chromosomal abnormalities, and brain tumors. The researchers excluded developmental disorders, perinatal complications, and pediatric disorders from the study.

Male veterans reported miscarriages more often, and the increase, 1.62 times, was statistically significant. Female veterans also reported more miscarriages, but the sample size of female veterans was too small to reach statistical significance. No attempt was made to relate these findings to DU or any other Gulf War exposure (36).

The studies of veterans with embedded shrapnel, done at the Baltimore, Maryland, Veterans' Hospital, reported finding DU in seminal fluid, indicating expected reproductive problems related to the genotoxic agent (37).

This information should have led the Gulf War veteran reproductive research to zero in on those veterans known to have been exposed to DU. Unfortunately, this opportunity to clarify the science in the large Gulf War study of reproduction has been lost.

## EMPIRICAL FINDINGS

Hari Sharma (38), professor emeritus from the University of Waterloo, tested some U.S., Canadian, and U.K. veterans, and Iraqi civilians from Basra and Baghdad, for urine DU about eight to ten years after the 1991 war. His findings, when DU was estimated from an isotopic analysis of the uranium present in a 24-hour urine sample, ranged from 81 to

1,340 nanograms of DU. This was surprising to those who trust the ICRP guidelines predicting a three-year biological half-life for insoluble uranium oxide. It was eight to nine years since the veterans' exposure to DU had terminated—approximately three biological half-lives of uranium oxide. Either the biological half-life estimate was wrong or the initial contamination exceeded any known credible estimate. Of the three Iraqi residents of Basra included in the study, the first had urine with 147 nanograms of DU, the second had no DU, and the third had 426 nanograms of DU. Of the five residents of Baghdad, the first had urine with uranium that was 20 percent DU; the second, 64 percent DU. The other three had all natural uranium in the urine (38). Microgram content could not be calculated for some samples. However, it is clear that the DU aerosol from the battlefield was transported to Basra and Baghdad, although there was no fighting there.

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## SUMMARY

In this prolonged and complex exposure picture, one cannot assume that cellular repair systems and hormonal systems will remain intact and function satisfactorily. Failing repair, radiation damage will increase, and cancer may well follow. When the biological half-life for a radioactive compound is wrong by such a large factor, as detailed here, the dose and cancer death risk calculations, based on old science, are unreliable. Much of the uranium oxide was in the nanoparticle size range and ceramic oxide form. The ceramic form would be expected to resist dissolution in body fluid, prolonging the biological half-time. Moreover, the dose from nano-particles cannot be estimated using the physics methodology described above. For one thing, these ceramic nano-particles cannot spread homogeneously in an organ, and for another, the contact dose is increased because of maximized surface area (for volume) and reduced self-screening. These particles remain point sources of internal (contact) dose until (if ever) they dissolve in body fluid. Ceramic nano-particles may well stay in the body for a lifetime.

The portion of DU excreted in urine may not correctly predict either the original internal contamination or the residual amount still stored in the body, as based on outdated formulas. Ceramic particles most likely do not bind to bone but continue to circulate in blood and lymph fluid, irradiating blood and lymph vessels and surrounding tissues. Nano-particles can even “hide” within cells, disrupting biochemical activities. If the ceramic DU does dissolve, it can bind to the phosphate in DNA or can be stored in bone, irradiating the stem cells involved in blood formation. DU can easily penetrate the blood-brain and reproductive barriers, contaminating brain tissue, seminal fluid, or the uterus, damaging the developing embryo or fetus. Because of their small size, DU particles resist filtering out by the kidneys.

The observed DU in urine eight or nine years after exposure may well be only the tip of the iceberg. Damage to the individual will occur not only from the inhaled DU aerosol but also from all the other toxic debris generated by the DU metal fume. Metal debris in the body, like debris from deteriorating hip implants, dental amalgams, or breast implants, has been shown to be detrimental. Hence the variety of symptoms reported by Gulf War veterans derives partially from the complexity, variety, and persistence of the foreign body invasions from their battlefield environment, not least of which was the DU-

caused metal fume.

Use of DU in battle is certainly a major contributor to this medical disaster that has affected at least one-third of U.S. Gulf War veterans.

## CONCLUSION

The problems of Gulf War syndrome are too complex for a reductionist methodology that extracts the toxic effect of a single component, even depleted uranium. Increased free radicals, heavy metal toxicity, the complexity and sensitivity of disrupted cellular reactions, damaged organelles, dysfunctional enzymes and hormones, and mycoplasma invasion—all occurring simultaneously within vital organs—pose monumental problems for function and survival. The mathematical methodology used by physicists is inappropriate for an insoluble nano-particle such as the ceramic DU internally deposited along with this toxic soup.

The standard mathematical calculation of the radiation risk of cancer death is likely misleading, because of the many other carcinogenic mechanisms, cellular repair dysfunction, and complex biochemical reactions not incorporated into the mathematics. For those veterans with illnesses resulting from internal radioactive contamination and multiple cellular dysfunction problems, who are trying to live normally and work to support their families, the radiation physics prediction of low radiation-related cancer death risk is likely both wrong and irrelevant. However, regulators will take the mathematical prediction very seriously when awarding compensation.

Veterans, and the medical personnel helping them, need to understand what happened in this war and what can be done to improve veterans' situations. They need medical, financial, and political help. I hope that some remedies will soon be found but, while waiting, I would suggest nature's own detoxifying method. Nature cleanses the soil with distilled water, evaporated by the sun and condensed in the clouds, falling as rain. Using distilled water for drinking could provide some relief to Gulf War veterans, as it did for many atomic veterans in the 1950s and 1960s. (See 39 for the successful use of distilled drinking and cooking water for children with iron-deficiency anemia caused by a uranium-contaminated environment.) Re-supplying the body's protein and mineral loss would also be helpful. Undenatured (organic) whey products can be taken to replace proteins, and stressing zinc, calcium, and magnesium products in the diet would also help.

Serious questions about the legality of DU, as used in war, also need answers. These cannot be provided by an isolated mathematical calculation of the DU exposure risk of radiation-related cancer death. In other words, the "trivial" number of calculated cancer deaths thought to have been caused will not make this weapon acceptable to the Geneva Protocols, or to ordinary people using common sense.

Individuals from many countries have joined their efforts to bring this issue to the Human Rights Tribunal of the United Nations (which consists of the U.N. Commission on

Human Rights, and the U.N. Sub-Committee on the Promotion and Protection of Human Rights) and have formed global organizations to support victims of DU and work toward a ban on its use. The special investigator of the Sub-Committee on the Promotion and Protection of Human Rights has found that the use of DU is illegal under existing Humanitarian Law. Yet millions of dollars have been spent on sending out fact-finding teams of experts from respected international agencies, all using the same ICRP outmoded guidelines and methodology, and all coming to similar irrelevant conclusions.

It is not disputable that DU powder produces an invisible metal fume. This alone is a violation of the Geneva Protocol on the Use of Gas (metal fumes constitute a gas) in War (Geneva, 1925), which was ultimately signed, with reservation (i.e., use for crowd control), by President Ford for the United States on January 22, 1975, and was proclaimed in the United States on April 29, 1975. The United Kingdom signed the protocol on April 9, 1930.

The commitment to this Geneva Protocol was clearly known by the United States and United Kingdom before the 1991 war against Iraq (40). The illegality arguments can be left to lawyers. However, disruption of biochemical processes, not an isolated mathematical estimate of DU radiation-related cancer deaths, must be the foundation of the legal claim of harm. Clearly, depleted uranium is at least partially responsible for a series of biochemical events that are significantly harmful to human beings. The damage is indiscriminate, caring not for national affiliation, age, gender, or status as combatant or civilian. In other words, DU is a weapon that destroys one's own military and the generally exposed civilian population, as well as enemy combatants. It renders the postwar civilian environment hazardous for many years to come—much like land mines, which are now banned.

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