A Primer in the Art of Deception

The Cult of Nuclearists, Uranium Weapons
and Fraudulent Science

by Paul Zimmerman

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Are Uranium Weapons Made of Uranium?

The twenty-first Century is a complex time in which to live. In previous eras, it was relatively easy to identify monstrous acts of savagery. If a barbarian horde rode roughshod over a community and slaughtered 50,000 people, there would be no room for debate as to whether or not an atrocity had been committed. But in this century, carnage can be subtle and sublime. Crimes against humanity are perpetrated in the atomic realm, silently and invisibly. Thunderless cannonade by photons and subatomic particles, set off within the depths of a human body, decimate biomolecular structures and initiate disease processes. Debilitating illness, cancer, birth defects: these are the types of devastations delivered by the nuclear war waged beneath a victim's skin.

Depleted uranium is devilish in its complexity. It is not a simple substance and does not behave, once inside the human body, in simple ways. Muddled thinking frequently obscures the subject, even by professionals who should know better. Frequently, those who write about DU err by rendering the topic overly simplistic. Others, with more sinister intentions, gloss over the details so as to hide the vectors of DU's toxicity.

In the Earth's crust, uranium is present in the form of three different isotopes. In terms of their relative concentration, 99.2749% is U-238, 0.7196% is U-235 and 0.0055% is U-234 (Dietz 1999a). Wherever this natural, non-depleted uranium is found, the radioisotopes in its decay series are also present. The decay products of U-238 include thorium-234, protactinium-234, uranium-234, thorium-230, radium-226, radon-222, polonium-218, lead-214, bismuth-214, polonium-214, lead-210, bismuth-210 and polonium-210. Stability is finally achieved for each atom when it transmutes into lead-206. The

decay chain of U-235 is different. Its daughter products include thorium-231, protactinium-231, actinium-227, thorium-227, radium-223, radon-219, polonium 215, lead-211, bismuth-211 and thallium-207. This series reaches stability with lead-207. The half-life of U-238 is 4.49 billion years. The half-life of U-235 is 710 million years. The third isotope of uranium found in nature is U-234. It is a decay product of U-238. It is much less abundant than the other two uranium isotopes, and its half-life is 245,000 years.

After uranium-bearing ore is mined, it is transported to a uranium mill. Here, the uranium is chemically separated from the other material present in the rock, including its daughter radioisotopes, and concentrated into a product called "yellowcake." Yellowcake, a coarse powder, is approximately 80 percent triuranium octaoxide (U_3O_8). This uranium has the same relative concentrations of U-238, U-235 and U-234 as the uranium found in nature. The next step in the uranium fuel cycle is the conversion of yellowcake into usable fuel for nuclear reactors or bombs. For a small number of reactors, such as the Canadian CANDU reactor, uranium need not be enriched. For these, fuel pellets are produced simply by converting the uranium in yellowcake to uranium dioxide (UO_2) metal. The majority of nuclear reactors, however, require slightly enriched uranium to sustain their chain reaction. To achieve this, the relative concentration of U-235 in a mass of uranium must be increased from 0.7196% to between three and five percent. Certain types of nuclear weapons also require enriched uranium, and for these, the relative concentration of U-235 must exceed 90 percent.

The process of uranium enrichment first requires yellowcake to be converted to uranium hexafluoride (UF_6). UF_6 is a solid at room temperature. When heated to 134° F (57° C), it sublimes, entering a gaseous state. Either through the gaseous diffusion or gas centrifuge process, the lighter atoms of U-235 are separated from the heavier atoms of U-238 and then concentrated. As a consequence of the enrichment process, two different products are produced: enriched uranium and depleted uranium. Both leave the enrichment facility as UF_6. Enriched uranium contains proportionally more U-235 than the uranium found in nature. Depleted uranium is only "depleted" of a portion of its U-235 content. The relative concentration of the three isotopes of uranium in depleted uranium is as follows: 99.7947% is U-238, 0.2015% is U-235 and 0.0008% is U-234. These numbers can be somewhat variable. The definition of depleted uranium by the Nuclear Regulatory Commission is uranium with a U-235 content less than 0.72%. The Department of Defense requires that uranium used for military purposes have a U-235 content of less than 0.3%.

The differences between non-depleted and depleted uranium may be visualized in the form of the following table, reproduced from the IAEA website. It is important to note

that, during the enrichment process, what becomes depleted uranium is diminished of not only U-235 but also U-234. In nature, nearly half of the radioactivity of non-depleted uranium comes from U-234. By contrast, U-234 contributes only 15.2 % to the radioactivity of DU.

Isotope	Natural Uranium By Weight	Natural Uranium By Activity	Depleted Uranium By Weight	Depleted Uranium By Activity
U-238	99.28%	48.8%	99.8%	83.7%
U-235	0.72%	2.4%	0.2%	1.1%
U-234	0.0057%	48.8%	0.001%	15.2%

The non-depleted uranium that is present in nature is, for the most part, found in low concentrations in soil, rock and water. Its concentration is routinely measured in parts per million. According to the IAEA:

> The average concentration of natural uranium in soil is about 2 parts per million, which is equivalent to 2 grams of uranium in 1000 kg of soil. This means that the top meter of soil in a typical 10m x 40m garden contains about 2 kg of uranium (corresponding to about 50,000,000 Bq of activity just from the decay of the uranium isotopes and ignoring the considerable activity associated with the decay of the progeny. Typical activity concentrations of uranium in air are around 2 μBq per cubic meter. (UNSCEAR 2000). Most of the uranium in water comes from dissolved uranium from rocks and soil; only a very small part is from the settling of uranium dust out of the air. Activity concentrations of U-238 and U-234 in drinking water are between a few tenths of a mBq per liter to a few hundred mBqs per liter, although activity concentrations as high as 150 Bq per liter have been measured in Finland (UNSCEAR 2000). Activity concentrations of U-235 are generally more than 20 times lower (IAEA).

In contrast to the diffuse, unconcentrated presence of non-depleted uranium in the environment, depleted uranium UF_6 is 100% uranium after being converted to depleted

uranium metal. Although this fact is routinely swept under the table in discussions on the toxicity of DU, it is immeasurably important. Proponents of DU frequently justify the safety of these weapons on the grounds that human beings are constantly exposed to uranium and show no ill effects. This argument is fancy footwork, but ultimately, hokum. DU munitions contain uranium in concentrations that are hundreds of thousands of times greater than the non-depleted uranium found in nature. Thus, for those internally contaminated with DU, an extremely enhanced chemical and radiological burden is introduced into their physiology which goes far beyond anything produced by exposure to naturally present non-depleted uranium. With the possible exception of a small number of workers in limited sectors of the uranium fuel cycle and some who are involved in the fabrication of components for nuclear weapons, **no human being on planet earth receives <u>acute</u> internal exposure to <u>concentrated</u> uranium at levels comparable to those who inhale particles of DU.**

For a proper understanding of the enhanced radiological hazard of depleted uranium and the skullduggery that surrounds the subject, the radioactive properties of naturally occurring non-depleted uranium and DU must be compared. In the following chart, measurements are given for the total radioactivity and alpha radioactivity of various forms of uranium. Measurements are presented in two different units: MBq/kg (million disintegrations per second per kilogram) and mCi/kg (thousandths of a curie per kilogram). With minor variations, the information in this chart is presented in every technical article and

Uranium	Activity [MBq/kg]	Alpha-Activity [MBq/kg]	Activity [mCi/kg]	Alpha-Activity [mCi/kg]
U-238	12.4	12.4	0.335	0.335
U-235	78.4	78.4	2.12	2.12
Natural, Non-depleted Uranium with daughter products	50.4	25.2	1.36	0.681
Depleted Uranium with daughter products	39.3	14.4	1.06	0.389

Reproduced from V.S. Zajic. Review of Radioactivity, Military Use, and Health Effects of Depleted Uranium

textbook discussing the radiological properties of uranium. The total activity and alpha activity for U-238 in columns one and two and columns three and four are identical because uranium's total activity is by alpha emissions. The same is true for U-235. The line to focus on in this chart is the third one which is meant to represent the combined activity of natural uranium and the radioisotopes in its decay chain. As can be read from the chart, one kilogram of this material decays at a rate of 50,400,000 disintegrations per second and emits 25,200,000 alpha particles per second. By comparison, as seen in line four, the total activity of DU with its decay products is 39,000,000 disintegrations per second per kilogram and it emits 14,400,000 alpha particles per second. Applying a little math to the figures in the chart, the discovery is made that **the total activity of DU is actually about 22% less than that of non-depleted uranium**. When the alpha activity is considered independently of the activity of the daughter products, which emit beta and gamma radiation, its radioactivity is 43% less. **It is this difference in alpha activity, *when the beta and gamma emissions are conveniently ignored*, which is the source for the commonly cited observation that DU is 40% less radioactive than non-depleted uranium.**

In virtually every article written on depleted uranium, the author mentions that DU is 40% less radioactive than natural uranium. Technically, as we have seen, this is true if we confine ourselves to comparing their alpha activity. But this simple statement obfuscates true understanding of the enhanced hazard presented by exposure to DU. Consequently, it is necessary to keep battering the wall of misconceptions so that no misunderstanding remains about the difference between natural exposure to non-depleted uranium and unnatural exposure to depleted uranium. For the sake of clarity, let's ask this question: Where can we find in nature a kilogram of this so-called "natural" uranium that undergoes 50,400,000 disintegrations per second. For some, the answer will be startling: **NOWHERE!** A kilogram of natural uranium with its daughter products cannot be found anywhere in nature. The idea of a concentrated mass of natural uranium is an abstraction. Scientists, whose stock-in-trade is to deal in abstractions, frequently overlook the fact that some of their abstractions represent nonsense in the real world. This is a case in point. What the scientist is saying with this abstraction is that if he could gather together and concentrate into a single, one-kilogram mass the uranium found in nature and its daughter products, the activity of this material would be that listed in the chart above. But a kilogram of this material doesn't exist in nature. Typically, uranium is found in soil or water as a few parts per million. Typical ore mined in the United States ranges from 0.05 - 0.3% uranium.

Once uranium-bearing ore is mined, it is transported to a mill where it is crushed and chemically treated in the first step of the refining process. At this point, the uranium

is separated from its decay products and possesses only 15 percent of the radioactivity that it would have had as concentrated "natural" uranium. The remaining 85 percent of the radioactivity is discarded in mountains of waste known as uranium mill tailings. After uranium is milled, it is shipped to conversion facilities where the uranium is put through further refining processes and then converted into concentrated, pure "natural" uranium. It is only at this point where "natural" uranium is truly born. This uranium will be composed of the three isotopes of uranium found in nature and will be more radioactive than DU due to its greater concentration of uranium-235 and uranium-234. When made into metal, the specific activity of this "natural" uranium is approximately 670 nanocuries per gram (Makhijani and Smith 2004). This activity translates into 24,790 disintegrations per second per gram. According to Makhijani and Smith: "The specific activity of DU can vary, but it is always greater than 340 [the specific activity of uranium-238] and less than 670 nanocuries per gram." In other words, the specific activity of DU falls within the range of between 12,580 and 24,790 disintegrations per second per gram.

So now we must ask: "Who exactly is it that is exposed to this so-called 'natural' uranium?" The number is relatively small: workers in certain sectors of the uranium fuel cycle, some employees at facilities producing components for nuclear weapons, some workers at chemical supply companies and perhaps some people in education, research or industry who use uranium and uranium compounds in the course of their work. Outside of this small subpopulation of human beings, no one on earth is exposed to "natural" uranium in any quantities other than the trace amounts found in nature. In contrast, all people present on the contaminated battlefield and those downwind are at risk of internal exposure to pure uranium metal. When this material is inhaled, the exposure is totally unnatural. The internalized particles are concentrated uranium. Once embedded in tissue, they act as point sources of radiation, and their level of radioactivity far exceeds that from naturally occurring uranium in the environment. **No one else on Earth receives such exposure to uranium as those contaminated by battlefield DU.**

Let's take it even further. If we did manage to acquire a kilogram of natural uranium, would it be more or less hazardous than a kilogram of depleted uranium? By conventional wisdom, the obvious answer would be non-depleted uranium because it is 22% more radioactive. But this is not true. We are once again dealing in irrelevant abstractions. Without question, the depleted uranium would pose the greater hazard. How can this be? Battlefield DU is put through a unique transformative process which masses of natural uranium never undergo. When DU munitions strike their target, they are burned and pulverized into microscopic-sized particles. This sets the stage for a unique exposure scenario. Of all possible configurations, a mass of material presents a greater and greater surface area when broken down into a collection of smaller and smaller particles. The inhalation of

pure uranium metal in the form of microscopic particles creates the maximum surface area for the quantity of uranium internalized to come into direct contact with the internal molecular architecture of the body. This geometry facilitates the greatest possible number of chemical interactions between the DU particles and nearby biomolecular structures and allows the maximum amount of radioactivity to escape the mass of each particle and bombard nearby cells. Such folly: after the expenditure of exorbitant amounts of money, energy and human labor to extract and concentrate the diffuse quantities of uranium found in nature, DU munitions redisperse uranium back into the environment, but this time, in a more toxic configuration.

If an honest comparison were to be made between typical human exposure to the uranium found in nature to the atypical exposure suffered by those inhaling the debris of DU weapons, one would discover that DU emits substantially more radioactivity. To help to clarify this, the specific activity of uranium isotopes in a gram of soil is 0.7 picocuries, or put more simply, **0.025 disintegrations per second per gram** (Todorov and Ilieva). The specific activity of 0.2% uranium ore is 4.0 nanocuries per gram (Makhijani and Makhijani 1996). This includes all decay products of uranium-238 up to and including radium-226, assuming they are in secular equilibrium with uranium-238. Mathematically, this translates into **148 disintegrations per second per gram**. Now to complete the picture, let us compare the radioactivity of these naturally occurring concentrations of uranium to the radioactivity of depleted uranium. For the sake of convenience, we can estimate the specific activity of depleted uranium to be 360 nanocuries per gram. This is a rough approximation. According to Makhijani and Makhijani:

> The radioactivity per unit weight (called specific activity) of depleted uranium metal is dominated by its principal constituent, uranium-238. It also depends somewhat on the exact extent to which uranium-235, and hence also uranium-234, have been separated and passed into the enriched uranium stream. It may vary from about 360 nanocuries/gram to about 450 nanocuries/gram. Even assuming that only uranium-238 remains, the specific activity would be still about 340 nanocuries/gram.

Using 360 nanocuries per gram as the specific activity of DU, this translates into **13,320 disintegrations per second per gram**. To receive equivalent exposure to this gram of DU, you would need to take into your body 532,800 grams of soil. Those who discount the hazard of DU based on the argument that humans are routinely exposed to uranium without ill effect are attempting to hypnotize humanity with balderdash.

It has so far been established that depleted uranium consists of the three naturally occurring isotopes of uranium. Although differing in their half-lives, each decays by emitting an alpha particle with an energy exceeding 4.0 MeV. As each atom decays, it transmutes into another element. Thus, with the passage of time, a mass of DU begins to accumulate trace quantities of its decay products.

When depleted uranium exits the enrichment facility, it is in the form of UF_6. At this point, it has been stripped of its decay products. According to Dietz (1999), when this uranium hexafluoride is chemically reduced to DU metal, the decay chain of uranium-238 is broken once again. The melting and reprocessing of this metal into DU ammunition breaks the decay chain yet another time. Thus, to inventory the decay progeny in battlefield DU, one must start from the time that DU munitions are manufactured. As each uranium-238 atom in a DU munition undergoes radioactive decay, it emits from its nucleus an alpha particle which consists of two protons and two neutrons. Thus, the newly transformed atom has an atomic number which has been reduced by two and a mass number which has been reduced by four. Thus, an atom of thorium-234 replaces each transmuted atom of uranium-238. With the passage of each second, thorium-234 begins to accumulate in freshly manufactured DU munitions. Simultaneously, atoms of this thorium-234 begin to undergo radioactive decay. The half-life of thorium-234 is relatively short, 24.10 days. When each atom decays, it emits a beta particle with an energy of approximately 0.20 MeV. It also emits a gamma ray of less than 100 keV. This beta decay transforms one neutron in the nucleus of a thorium atom into a proton. Thus, its decay product, protactinium-234m, has an atomic number one greater than the thorium isotope but a mass number that remains the same. Protactinium-234m has a half-life of 1.17 minutes. It also has two decay states. (The "m" represents "metastable" and indicates that the nucleus exists in an excited state.) Over 99% of the time, protactinium-234m decays to uranium-234 by emitting a beta particle with an energy of 2.29 MeV. This transformation is accompanied by the emission of a gamma ray with an energy of approximately 1.0 MeV. Less than one percent of the time, protactinium-234m undergoes an isomeric transition, reducing the extra energy in its nucleus from its excited meta state to its ground state, by emitting a gamma ray of 0.0694 MeV. Transformed now into protactinium-234, it has a half-life of 6.7 hours. When decaying to uranium-234, it emits a beta particle of 0.23 MeV.

The significance of the gamma emissions from DU is eloquently described by Dietz and deserves repetition:

> Gamma rays become absorbed in body tissue as follows. If their energy exceeds 40 keV, part of the gamma-ray energy is transferred to an atomic electron, setting it in high-speed motion (1 keV = 1000 electron

> volts energy). The remaining energy is carried off by a new gamma ray. This process, called the Compton effect, repeats until the gamma ray has an energy below about 40 keV where the photoelectric effect dominates and the remaining energy can be transferred to a photoelectron. For example, using Gofman's method (Gofman 1990), one can calculate that an 850 keV gamma ray absorbed in body tissue will produce a packet of high-speed Compton electrons and a fast photoelectron that on average can traverse 137 body cells. By contrast, according to Gofman, X-rays commonly used in medical diagnosis have a peak energy of 90 keV and an average energy of 30 keV (Gofman 1990). A 30 keV X-ray in body tissue can be converted into a photoelectron of this energy, which on average can traverse only 1.7 cells. Ionization along the tracks of high-speed electrons in tissue can cause damage to genetic material in the nuclei of cells. Thus, a high energy gamma ray from Pa-234 is much more penetrating than a typical medical X-ray and can damage far more living cells. The many 2.29 MeV beta particles emitted by Pa-234 are extremely penetrating in body tissue (1 MeV = 1 million electron volts energy). Referring to the experimental data given by Gofman (Gofman 1990), each one of these beta particles can traverse more than 500 body cells.

Depleted uranium, we now have discovered, consists not only of the three naturally occurring isotopes of uranium but also trace quantities of thorium-234 and protactinium-234m (or protactinium-234). These isotopes, due to their short half-lives, add to the radioactivity emitted by DU. When a DU penetrator is manufactured, it is stripped of the decay progeny of uranium. It consists of over 98 percent uranium-238 with the remainder consisting of uranium-235 and uranium-234 and the other nonradioactive metals with which it is alloyed. Within this mass, as the uranium-238 decays, the presence of thorium-234 and protactinium-234m begins to increase. Each second, using Dietz's numbers, a gram of uranium-238 undergoes 12,430 disintegrations per second. What needs to be established is the rate of decay among the increasing population of thorium and protactinium atoms. Interestingly, a state of "secular equilibrium" is reached within a relatively short period of time. Secular equilibrium is achieved only when an isotope with a relatively long half-life decays into a daughter isotope with a half-life that is much shorter. As the parent isotope decays, the population of the daughter isotope increases. However, due to its own rate of radioactive decay, the daughter population is simultaneously decreasing. When the population of the daughter isotope reaches a level where it is decaying at the same rate that it is being produced, so that overall, its quantity remains constant, secular equilibrium is achieved. Secular equilibrium occurs between uranium-238 and thorium-234 when they begin undergoing the same number of disintegrations per second, 12,430. Similarly, secu-

lar equilibrium is established between thorium-234 and protactinium-234m. By the end of 30 weeks, all three isotopes are disintegrating at the same rate. (Because the half-life of uranium-234 is 246,000 years, its presence does not increase rapidly enough to further add to the radioactivity of a mass of uranium-238.) Dietz presents the progression toward secular equilibrium in a mass of uranium-238 in the chart below.

Radioactivity (disintegration per second) in one gram of uranium-238 with no decay progeny initially present.

Weeks	U-238	—>	Th-234	—>	Pa-234	—>	U-234
0	12,430		0		0		0.000
1	12,430		2,270		2,150		0.000
5	12,430		7,890		7,840		0.001
10	12,430		10,770		10,750		0.004
15	12,430		11,830		11,820		0.007
20	12,430		12,210		12,210		0.010
25	12,430		12,350		12,350		0.013
30	12,430		12,400		12,400		0.017

The significance of this chart must be grasped if one wishes to fully understand the enhanced radiological hazard of depleted uranium when compared to the less concentrated forms of uranium found in nature. A gram of uranium-238 which has been stripped of its decay products emits 12,430 alpha particles per second. With the passage of time, the growing population of thorium-234 and protactinium-234 begins undergoing radioactive decay, and with each disintegration, each isotope emits a beta particle and a gamma ray. By the time 30 weeks have elapsed, all three isotopes are decaying at the same rate. At this stage the gram of uranium-238 at each second is emitting 12,430 alpha particles, 24,860 beta particles and 24,860 gamma rays.

Often one reads that the alpha emissions from a particle of DU are only capable of traversing a few cell diameters. Thus, only cells in the immediate vicinity of an embedded particle are at risk of injury or destruction. But this conception is incomplete. A particle of DU is continuously emitting alpha, beta and gamma radiation in a spherical volume

around the particle that encompasses hundreds of cell diameters. The inhalation of hundreds of thousands or millions of such particles creates a situation where a large number of body cells surrounding each particle are exposed to an ongoing barrage of radiation which may continue for years. Only by relying on the fraudulent concept of "dose" can those who advocate for the use of DU weaponry discount as insignificant this open-ended assault on biology.

The radioactivity of depleted uranium is further enhanced by the spontaneous fission of uranium-238. Spontaneous fission is a form of radioactive decay where the nucleus of a heavy atom spontaneously splits into two smaller nuclei. The byproducts of this process include free neutrons, gamma rays and other nuclear fragments such as alpha and beta particles. This event is relatively rare, but it might nonetheless have important biological consequences when occurring inside the human body. According to the European Nuclear Society, within each gram of uranium-238, one atom undergoes spontaneous fission every 2.5 minutes. This translates into roughly 210,240 spontaneous fission events per gram per year. This highly energetic process releases nearly 40 times the energy of the radioactive decay of a uranium atom. Thus, each spontaneous fission event of internalized DU releases approximately 160 MeV into tissue.

We have inventoried the radioisotopes in a mass of depleted uranium and presented a basic picture of their radioactivity. In a better world, this chapter would now be concluded. But DU is an insidious weapon with many stories to tell. The quickest entrance into one of America's dirty little secrets is by way of a riddle: In 1999, what did our NATO allies fighting in Kosovo and workers at the Paducah Gaseous Diffusion Plant in Kentucky have in common? Answer: They both learned for the first time that their exposure to "uranium" included exposure to the transuranic isotopes americium-241, neptunium-237, plutonium-238, plutonium-239, the fission product technicium-99 and the fission activation product uranium-236. In the case of Kosovo, this discovery came in the aftermath of the war when two laboratories analyzing spent DU rounds discovered traces of plutonium. Disclosure of this finding ignited the ire of representatives of NATO countries who had been kept oblivious of the fact that DU was something other than it seemed. At Paducah, workers also learned that the uranium with which they worked was contaminated, and this generated concern that this material might have accumulated to unsafe concentrations at various work stations throughout the plant. In response, the Department of Energy undertook a study which was first published in 2001 as "A Preliminary Review of the Flow and Characteristics of Recycled Uranium Throughout the DOE Complex: 1952-1999." This study let the whole world in on the secret that the entire US stock of depleted uranium was contaminated with transuranics and fission products.

As the DOE tells the story, uranium was scarce relative to demand when the United States began developing nuclear weapons. In 1952, as the Cold War began in earnest and bomb production accelerated, a program was initiated at the Hanford Site in Washington State for recovering uranium from spent reactor fuel, targets and discarded high-level radioactive waste. In time, recovery programs spread to the Idaho National Engineering and Environmental Laboratory, Idaho; the Savannah River Site, South Carolina; and the West Valley Demonstration Project, New York. Chemical separation plants at these four sites separated, concentrated and recovered plutonium and uranium from the fission products and other transuranic isotopes which had accumulated in the spent nuclear fuel and targets. However, separation was never 100%, and the recovered uranium contained trace concentrations of plutonium, other transuranics and fission products. From the chemical separation plants, the contaminated uranium flowed to three principal types of processing facilities: the gaseous diffusion plants, the feed manufacturing facilities and the component fabrication facilities. The eight sites involved were the Paducah Gaseous Diffusion Plant (GDP) , Kentucky; the Oak Ridge GDP, Tennessee; the Portsmouth GDP, Ohio; the Feed Materials Production Center at Fernald, Ohio; the Oak Ridge Y-12 Complex, Tennessee; the Rocky Flats Plant, Colorado; the Weldon Spring Site Remedial Action Project, Missouri; and Reactive Metals, Inc., Ohio.

Between March 1952 and March 1999, the four chemical separation plants shipped 130,000 metric tons of the impure recycled uranium to the processing facilities. At the three gaseous diffusion plants and the feed manufacturing facilities, this uranium was blended with natural uranium that had never before been through a reactor. This raised the total inventory of the contaminated product in the DOE complex to 250,000 metric tons of recycled uranium. At the three gaseous diffusion plants, the contaminated recycled uranium was fed into the enrichment process. A portion of the transuranics and fission products contained in this feed material entered into the depleted uranium stream. This was the source for the contaminated DU now scattered in Iraq, Bosnia and Kosovo and many gunnery ranges throughout the United States.

The exact composition of the DU being scattered around the globe is open to question. Hints of this come from the DOE:

> The flow of uranium among DOE sites and within various streams at individual sites was extremely complex. Processing sites used recycled uranium to create materials for reactor fuel and weapons components and shipped the materials to other DOE sites. Since processing normally required multiple steps and production optimization, the sites also interchanged materials among themselves. Operations within

> DOE frequently and deliberately concentrated the isotopes, diluted them, and blended them with natural uranium, in some cases increasing the total amount of uranium containing transuranics/fission products in the complex. **Data on transuranics/fission product levels are incomplete; DOE did not track the trace quantities of transuranics and fission products other than ensuring plutonium concentration to be less than the 10 per billion specification** [emphasis added] (US DOE).

There is no uniformity in the composition of DU. One batch may differ significantly from another. DOE claims that within the current inventory of DU only trace concentrations, measured in a few parts per billion, are present of neptunium-237, plutonium-238, plutonium-239, plutonium-240, americium-241 and technicium-99. In the absence of analysis by independent parties, the public is forced to accept affirmations by the DOE that the concentration of plutonium in DU is less than one part per billion, that of neptunium-237 is less than five parts per billion and that of technicium is less ten parts per billion. Analysis of a small number of DU munitions recovered in Kosovo revealed similar trace levels. Cautiously, the Royal Society offers this observation: "However, independent analyses of the levels of these contaminants in DU munitions are required to confirm that the reported levels are not significantly exceeded in other batches of penetrators." According to the WHO, the radiation dose from the transuranic and fission product contamination of DU contributes less than a one percent increase in the radioactivity of a DU munition.

Objective nature is a tool for truth in a world of falsehood. When uranium is present in a nuclear reactor, the nuclei of atoms of uranium-235 capture neutrons and are transformed into uranium-236. Uranium-236 does not occur in nature. However, it is present in DU munitions manufactured from recycled uranium. Thus, its presence is a signature that the uranium in biological samples originated not from nature but exposure to depleted uranium waste from the nuclear fuel cycle. Contamination with uranium-236 testifies in every instance that exposure to weaponized uranium has occurred.

Depleted uranium is a witch's brew of radioisotopes. And yet, these do not complete DU's toxicological profile. DU munitions are the delivery vehicle for a much broader inventory of toxic chemical compounds. These will be discussed in the chapter devoted to the health effects of DU. Enough has been revealed, however, to raise an important point. Depleted uranium is a unique hybrid for which no natural or manmade analogue exists. As such, the relevance of much of the research cited to demonstrate that exposure to DU produces no malignant effects needs to be questioned. Uranium miners or people living in areas with unusually high levels of uranium in soil and water are receiving, both

qualitatively and quantitatively, a different type of exposure than those who inhale battlefield DU. Granted militarized uranium is approximately 98 percent uranium-238. Nonetheless, it is more concentrated, more radioactive and laced with trace quantities of a number of unnaturally occurring radioisotopes. No other example of uranium exposure is sufficiently analogous to reasonably be used as a substitute to explain away DU's toxicity. Thus, much of the pre-1991 research on uranium exposure may be irrelevant in assessing the medical effects of DU.

Similarly, since the First Gulf War, a renewed interest has arisen in the toxicology of uranium. New research is being conducted in numerous labs throughout the world. This is valuable work and needs to be encouraged. However, when one reviews the published literature, a glaring deficit emerges. Nearly all of the research initiatives are based on *in vitro* and *in vivo* studies using a variety of purified chemical compounds of uranium. These compounds are acquired from chemical supply companies. Although useful for investigating the chemistry and radiological effects of uranium, these may fall short in reproducing the biological effects produced by depleted uranium munitions. Battlefield DU is a dirty material. A realistic picture of its toxicity may not emerge from studies relying upon purified compounds of uranium. Consequently, spent rounds of depleted uranium and battlefield debris contaminated with DU must be the substances used to evaluate the toxicity of militarized uranium.

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