

## Costs and Risks of Depleted Uranium from a Proposed Enrichment Facility

BY ARJUN MAKHIJANI AND BRICE SMITH

Currently some 740,000 tons of depleted uranium, in unstable hexafluoride form, are stockpiled at three U.S. Department of Energy sites – Paducah in Kentucky, Portsmouth in Ohio, and Oak Ridge in Tennessee. The depleted uranium is a by-product of the uranium enrichment process that was carried out at the three sites over the past 60 years. The Portsmouth plant is in standby and the Oak Ridge plant has been permanently shut. The plant at Paducah is the only operational uranium enrichment facility in the United States. It is run by the United States Enrichment Corporation, the U.S. subsidiary of USEC.

LES, a corporate consortium led by the European company Urenco, wants to build a new uranium enrichment plant. The proposed plant, if built, would be located in Lea County, New Mexico, and would enrich uranium for fuel for U.S. nuclear power plants. USEC is seeking to build a similar plant in Ohio.

LES's license application to the U.S. Nuclear Regulatory Commission (NRC) constitutes the company's fourth attempt to build a uranium enrichment plant in the United States. The first attempt, which was for a plant in Louisiana, cost LES more than \$30 million. LES withdrew the application after a citizen's group successfully challenged the NRC's environmental impact statement for the project, called the Claiborne Enrichment Center, on environmental justice grounds. Two other locations, both in Tennessee, were also explored but abandoned in the face of local opposition. Disposal of the depleted uranium that would be generated in the enrichment process has remained a central public concern throughout.



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*A depleted uranium hexafluoride (DUF<sub>6</sub>) storage cylinder with external corrosion (rust) and a patch used to repair a breach, Portsmouth Gaseous Diffusion Plant, Portsmouth, Ohio. More than 16,000 DUF<sub>6</sub> cylinders (approx. 195,000 metric tons) are currently stored at the Portsmouth plant. An additional 36,000 cylinders are stored at the Paducah Gaseous Diffusion Plant in Paducah, Kentucky, and nearly 5,000 more at the Oak Ridge site in Oak Ridge, Tennessee.*

## Emerging Picture of Uranium's Health Risks

BY BRICE SMITH AND ARJUN MAKHIJANI

Uranium, including depleted uranium (DU), is usually most dangerous to people when it gets inside the body, whether through ingestion, inhalation, or through breaks in the skin (though prolonged contact can also result in significant external radiation dose). Inside the body, uranium creates risks both as a toxic heavy metal and as a radioactive material. Additionally, there are some indications that synergisms might exist between these two types of health effects.

Current federal safe drinking water regulations limit the concentration of uranium in drinking water to 30 micrograms per liter (mg/L) based primarily on its chemical toxicity. For natural uranium, this limit translates into 20 picocuries per liter (pCi/L) of radioactivity

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This article is based on an IEER report that assesses the problems associated with management and disposal of depleted uranium that would be generated by the proposed LES plant. The report was prepared for the public interest groups Nuclear Information and Resource Service (NIRS) and Public Citizen for use in their legal intervention in the licensing proceeding of LES. A redacted version of the report, excluding proprietary LES corporate financial data, was released to the public in February 2005. References for this article can be found in the report, *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES*, which is available online at [www.ieer.org/reports/du/LESrptfeb05.pdf](http://www.ieer.org/reports/du/LESrptfeb05.pdf).<sup>1</sup> This article also discusses an NRC ruling issued subsequent to and in response to the IEER report as well as legal issues raised by NIRS and Public Citizen.

### Uranium enrichment

Enrichment is the process of increasing the proportion of the isotope uranium-235 in uranium. Feeding natural uranium into an enrichment plant produces two output streams. One is the enriched stream,

### LOW-LEVEL WASTE

Commercial low-level radioactive waste (LLW) in the U.S. is defined by what it is not. According to Nuclear Regulatory Commission (NRC) regulations, low-level waste is "radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material [i.e., uranium or thorium mill tailings]..."

The "low-level" radioactive waste category thus includes everything from slightly radioactive trash (such as mops, gloves, and booties) to highly radioactive activated metals from inside nuclear reactors. It includes both short-lived and long-lived radionuclides.

NRC regulations sub-divide commercial low-level waste into four classes which are determined by the types of radionuclides and their concentrations which make up the waste. These classes are labeled Class A, Class B, Class C, and Greater Than Class C.

**Class A** waste is the least radioactive on average, and is contaminated primarily by what the NRC terms "short-lived" radionuclides.

**Classes B and C** are more radioactive: Class B may be contaminated with greater amounts of "short lived" radionuclides than Class A, and Class C with greater amounts of long-lived and short-lived radionuclides than Class A or B.

**Greater Than Class C** waste is typically much more radioactive than the other classes, and generally is considered unacceptable for near-surface disposal, which is how Classes A, B, and C are generally disposed of in the U.S. Shallow-land disposal used to be simple dumps mainly, but the concept now also includes more elaborate structures.

Source: Makhijani and Saleska, *High-Level Dollars, Low-Level Sense*, IEER (New York: Apex Press, 1992).

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which is used for fuel (after further chemical and physical processing), and the other is depleted uranium, so called because it is depleted in U-235.

There are various types of processes that can enrich uranium. The commercial ones require that uranium be put in a chemical form known as uranium hexafluoride ( $UF_6$ ). When heated to modest temperatures,  $UF_6$  sublimes into a gas.  $UF_6$  gas, when passed through a diffusion barrier or a centrifuge of appropriate design, can yield the two streams — enriched and depleted uranium — that are the final output of an enrichment plant.<sup>2</sup>

### Depleted uranium: Resource or waste?

As stocks of DU have continued to grow, the issue of its management and disposal has become more important. No final disposal strategy has been chosen or fully analyzed by the Department of Energy (DOE) for its depleted uranium stockpile discussed above. In fact, no disposal facility for large quantities of DU has been opened anywhere in the world. The DOE is still considering possible, but unlikely, uses for its DU.

Prior to this year, depleted uranium (DU) was actually classified by federal regulators as a “source material” (as is naturally occurring uranium ore) rather than as nuclear waste.<sup>3</sup> In January 2005, the NRC reviewed the issue of how DU from a uranium enrichment facility should be categorized if it was to be disposed of. The NRC ruled on January 18 that DU, if destined for disposal, should be considered low-level waste.<sup>4</sup> The NRC’s ruling was issued in response to the IEER report on which this article is based.

The NRC ruling formally changed the status of DU, but left some ambiguity as to how it can be disposed of. The staff of the Commission considers DU that is destined for disposal “Class A” low-level waste because it is not specifically included in the language of the regulations governing Class B, C, or Greater Than Class C (GTCC)

waste. (See the box on page 2 for definitions of the various types of low-level waste.) The Commission itself, however, ruled more generally, that because DU is not high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material, it should be broadly categorized as “low-level waste,” but made no ruling on how it relates to the specific classifications in the regulation.

In terms of its radiological properties, depleted uranium cannot be considered analogous to Class A low-level radioactive waste or to naturally occurring uranium ore. DU is most directly analogous to GTCC or transuranic (TRU) waste. Federal regulations define TRU waste as that which has a specific activity of more than 100 nanocuries per gram (nCi/g) of long-lived transuranic radionuclides that emit alpha radiation (plutonium, for example). DU has a specific activity of about 300 to 400 nCi/g, when accounting for the activity of all three uranium isotopes.

TRU waste is similar to the GTCC waste classification in terms of treatment of long lived alpha emitters.<sup>5</sup> The important element of the classification with respect to this discussion is the limit of 100 nCi/g of transuranic elements. TRU waste from DOE facilities is now being disposed in a deep geologic repository in New Mexico called the Waste Isolation Pilot Plant, a multi-billion dollar federal government project.

The similarity of DU to TRU waste was noted in a National Research Council report, both in regards to radiological characteristics and the difficulties associated with their disposal:

If disposal [of depleted uranium oxide] is necessary, it is not likely to be simple. The alpha activity of DU is 200 to 300 nanocuries per gram. Geological disposal is required for transuranic waste with alpha activity above 100 nanocuries per gram. If uranium were a transuranic element, it would require disposal in the Waste Isolation Pilot Plant (WIPP) based on its radioactivity. The chemical toxicity of this very large amount of material would certainly become a problem as well.<sup>6</sup>

**TABLE 1: SPECIFIC ACTIVITIES OF VARIOUS CHEMICAL FORMS OF DEPLETED URANIUM, OF TRU WASTE, AND OF TYPICAL URANIUM ORE WITH 0.2% NATURAL URANIUM BY WEIGHT**

Chemical form	Specific activity, nCi/gm
uranium metal (DU)	400
uranium dioxide ( $DUO_2$ )	350
uranium oxide ( $DU_3O_8$ )	340
transuranic activity in TRU or GTCC waste (see note)	>100
0.2% uranium ore	4 (See note)

Note: The specific activity shown for 0.2% uranium ore includes all decay products of uranium-238 up to and including radium-226, assuming they are in secular equilibrium with uranium-238. Radon-222 and its decay products are not included in this number. All values in the table are given in round numbers. Slight differences between the U.S. Environmental Protection Agency’s definition of TRU waste and NRC’s definition of GTCC (Greater Than Class C) waste as it relates to transuranic radionuclides are not material to this discussion because DU is comparable to either one.

Table 1 shows that depleted uranium in its chemical forms relevant to disposal have higher activities than the limit for TRU waste. The specific activity and the total amount of DU to be created by the proposed LES uranium enrichment facility are among the most important factors in considering its health and environmental impacts and ultimate costs.

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When considering the long-term impacts of disposing of depleted uranium, it is also important to consider the ingrowth of uranium daughter products. In addition to an increase in the amount of U-234 present in the DU, two other important daughter products of U-238 that must be considered are thorium-230 and radium-226. The ingrowth of additional long-lived alpha-emitting radionuclides adds further justification for treating DU as analogous to TRU waste.

In fact, the risks in terms of mortality per becquerel of intake of DU, including its decay products, are together about four times more dangerous than that of plutonium-239, as shown in Table 2. The table also illustrates that, when adjusted for the greater specific activity of  $DU_3O_8$  relative to the 100 nanocuries per gram threshold of TRU waste, the risk of each of the isotopes in depleted uranium (uranium-238, uranium-234, thorium-230, and radium-226) exceeds the risk of plutonium-239. Together, DU and its primary decay products are about an order of magnitude more risky (in terms of cancer mortality per unit of mass consumed) than TRU waste made up of 100 nanocuries per gram of plutonium-239.

Further, uranium and its decay products (with the

possible exception of thorium-230) have, in general, comparable or greater environmental mobility than plutonium.

Hence, from a regulatory point of view as well as from a scientific point of view, the risks that would arise from DU disposal cannot be considered as less than those from TRU waste disposal. The labeling of DU as low-level waste or Class A waste will not diminish its dangers. The Commission's ruling that waste DU is low-level waste should not be interpreted to mean that DU is suitable for shallow land disposal under 10 CFR 60.55(a), as are some types of low-level waste.

The Commission's ruling is not as objectionable as the NRC staff's position that waste DU should be categorized as Class A waste. The disposal of Class A waste, which is generally less radioactive or contains shorter lived isotopes than other waste classes, is regulated in a less protective manner than other classes of low-level waste. The regulations specify that the estimated dose to humans from the disposal of low-level waste must not exceed 25 millirem per year (mrem/yr).<sup>7</sup>

Shallow land disposal for TRU or long-lived GTCC wastes is generally not considered appropriate. These wastes typically require deep geologic disposal. In the Claiborne Enrichment Center case, the NRC staff took the position that depleted uranium in the form of  $U_3O_8$

**TABLE 2: COMPARISON OF MORTALITY PER BECQUEREL (Bq) AND MORTALITY PER GRAM OF DEPLETED URANIUM OXIDE AT SECULAR EQUILIBRIUM TO THAT OF 100 nCi OF PLUTONIUM-239 (I.E. THE AMOUNT CONTAINED IN TRU WASTE AT 100 nCi PER GRAM)**

	Uranium-238	Uranium-234	Thorium-230	Radium-226	Depleted uranium — total mortality ratio at secular equilibrium	Plutonium-239
Mortality per Bq for Tap Water Intake	1.13E-09	1.24E-09	1.67E-09	7.17E-09		2.85E-09
Mortality per Bq for Dietary Intake	1.51E-09	1.66E-09	2.16E-09	9.56E-09		3.63E-09
Mortality Ratio per Bq versus Pu — Tap Water	0.40	0.44	0.59	2.52	<b>3.93</b>	
Mortality Ratio per Bq versus Pu — Dietary	0.42	0.46	0.60	2.63	<b>4.11</b>	
Mortality Ratio, per gram of DU compared to a gram of TRU waste with Pu-239 at 100 nCi/g — Tap Water	1.34	1.48	1.99	8.53	<b>13.34</b>	
Mortality Ratio, per gram of DU compared to a gram of TRU waste with Pu-239 at 100 nCi/g — Dietary	1.41	1.55	2.05	8.93	<b>13.94</b>	

Note: "E-09" is another way of writing " $\times 10^{-9}$ ". The source for the drinking water and dietary mortality ratios is EPA Federal Guidance Report 13. The two bottom rows show the ratio of the mortality coefficients for uranium and its daughter products versus plutonium-239 after adjusting to account for the greater specific activity of bulk  $DU_3O_8$  relative to that of the transuranic elements at the threshold of TRU waste.

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powder was Class A low-level waste. However, the NRC staff's own analysis in the CEC Final Environmental Impact Statement (CEC FEIS) showed that shallow land disposal would result in doses in excess of the 25 mrem/yr limit, which is the regulatory limit for exposures to the public from the nuclear fuel cycle.

Adding further to the issue of waste classification is the possibility that the recognized chemical toxicity of uranium and the recent work exposing additional concerns regarding DU's effects in the body (described below and in more detail in the accompanying article) may cause depleted uranium to be treated as mixed waste that would, in part, be covered by the considerations of the Resource Conservation and Recovery Act.

### Doses from DU disposal

LES has described two options for deconversion<sup>8</sup> and disposal of the  $\text{DUF}_6$  tails that would be produced by the proposed enrichment facility:

- (1) the use of DOE facilities once the government's stockpile of  $\text{DUF}_6$  has been deconverted,<sup>9</sup> and
- (2) the construction of a private deconversion plant to handle just the volume of  $\text{DUF}_6$  to be produced by the proposed LES enrichment plant.

IEER has concluded that neither option as stated in the NRC's Draft Environmental Impact Statement (DEIS) for the LES plant<sup>10</sup> can be considered a plausible strategy for the disposition of the depleted uranium tails that would result from operation of the proposed enrichment facility. Given DOE's poor track record and failure to live up to its obligations, notably in the Yucca Mountain case,<sup>11</sup> as well as the large amount of its own DU that must be managed, the uncertainties arising from a DOE option are such that it could not be considered a credible strategy even if a written commitment could be obtained from the DOE to the effect that it would accept the DU from LES.

On the other hand, if LES used a private deconversion facility, the company would be responsible for DU disposal. In this case, LES may consider shallow land disposal at a site in Utah (Envirocare), or at a site in Texas just across the border from the proposed LES plant in New Mexico (Waste Control Specialists). However, no analysis of shallow disposal sites is included in the NRC's DEIS.

### NRC dose estimates — deep disposal

The current DEIS proposes that the DU generated by the proposed LES plant be disposed in an exhausted underground mine. The DEIS estimates projected doses to the general public (i.e., how much uranium would

accumulate in a person's body as a result of living on top of such a mine and drinking the ground water) and states that the dose estimates are greatly below the regulatory limit of 25 mrem/yr. NRC says these estimates are based on those from the 1994 CEC FEIS. Despite this assertion, the NRC has failed to provide IEER with the methods and assumptions underlying the dose calculations. The details of the CEC FEIS calculation are apparently no longer available, even to the NRC itself.

This is important because the doses from U-238 estimated in the CEC FEIS for deep (mine) disposal are incredibly low (literally). For instance, the drinking water dose estimated from the disposal of tens of thousands of metric tons of pure  $\text{DU}_3\text{O}_8$  powder in a mine was estimated by the NRC in the CEC case to be a million to a trillion times lower than typical background levels caused by the small amounts of uranium naturally present in water.

IEER's estimates indicate that the NRC's dose estimates are likely to be wrong by many orders of magnitude. However, a complete demonstration of the problems in the NRC's calculations is not possible due to the failure of the NRC to provide the methods and details of its calculations concerning the proposed LES facility.

### IEER dose estimates — deep disposal

In light of the NRC's apparent inability to share its calculations, IEER made simple estimates of potential doses that would be received by a hypothetical individual living on top of a mine in which DU had been disposed. We assumed that water would enter the mine and reach equilibrium with the depleted uranium powder (i.e., we assumed that a long enough time had passed for all relevant chemical reactions to have taken place). This calculation was repeated both with and without the presence of carbon dioxide (i.e., air) in the mine. We assumed that all drinking water would be derived from a well drilled into the mine.

The drinking water dose from U-238 alone under these conditions was estimated in the range of tens of millirem per year. The current drinking water limit, for all radionuclides, is 4 mrem/yr. The dose from the other uranium isotopes and the other decay products would add to the total potential dose. We also found that the amount of U-238 in the water in the mine would be approximately 6 to more than 20 times the current EPA drinking water limit of 30 micrograms of total uranium per liter ( $\mu\text{g}/\text{L}$ ).

For comparison, we calculated that if just one part in a million of the uranium dissolved in the water filling a mine with a volume of 20,000 cubic meters reached the drinking water,<sup>12</sup> the implied dilution required to reduce

No disposal facility for large quantities of DU has been opened anywhere in the world.

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the dose from U-238 to the levels given by the NRC calculation in the FEIS for disposal in a sandstone/basalt mine would exceed the volume of water in all of the Great Lakes combined.<sup>13</sup>

Our analysis indicates that it is reasonable to consider the NRC's well water scenarios in the CEC case (and therefore also in the present LES case) as scientifically improbable and likely wrong in one or more respects. A final determination of this issue cannot be made until the NRC actually provides all the details concerning their calculations including which models were used, how those models were run, and all of the various assumptions that were made in regards to the site, the model parameters, and the exposure scenarios. The NRC has so far failed to back up its claims that radiation doses from depleted uranium disposal in an abandoned mine would be within regulatory limits. Data-free analysis ought to be unacceptable in any forum, but it is especially so in an environmental impact statement prepared by a government agency charged with protecting public health and safety.

Our screening calculations show that generic calculations are not a plausible basis for assuming that disposal in some unspecified mine can meet radiation dose criteria or other health standards. Detailed site-specific evaluations are necessary when considering the disposal of depleted uranium.

### IEER dose estimates — shallow land disposal

In addition to the considerations of deep disposal, IEER also made a number of test runs of various scenarios using ResRad to estimate doses under various assumptions for shallow land disposal of DU in a presently arid climate.<sup>14</sup> The modeling program ResRad created at Argonne National Laboratory has been accepted by the NRC for use in performing dose calculations in support of nuclear facility decommissioning. In these test runs we have retained the default assumption of ResRad that considers a "reference man" (a 154 lb. adult white male) in its evaluation of radiation exposure. This assumption does not take into account that children are likely to be a

more sensitive population to both the chemical and radiological effects of uranium. However, as we will show below, shallow disposal of uranium is highly unlikely to be able to meet health and safety regulations even for the reference man.

The results of these very basic screening calculations are shown in Table 3. Significantly, all of the results are several orders of magnitude greater than the regulatory limit of 25 mrem/yr (or 0.025 rem/yr). They indicate that shallow land disposal is also not a plausible disposal strategy.

We do not claim that our calculations are in any way exhaustive or definitive. On the contrary, they are very simple screening calculations with many default and generic assumptions aimed at helping to address (a) whether the NRC calculations in the CEC FEIS are reasonable and supportable given that they are claimed to have been derived by the same mechanism as the estimates in the current LES DEIS and (b) whether generic calculations are a reasonable basis for estimating compliance with the existing regulations. As noted above, the answer to both is very likely to be no.

To its credit, the NRC, in its January 2005 ruling, agreed with IEER's argument that DU is dangerous enough that a disposal method cannot be decided without further analysis:

A more difficult question — and one we need not answer today — concerns whether the LES material, in the volumes and concentration proposed, will meet the Part 61 requirements for near-surface disposal. The Commission agrees with the intervenors that a definitive conclusion on this and other disposal method questions cannot be reached at this time, and may require further environmental or safety analysis. Our decision should not be read to intimate any Commission view on this issue, which relates both to the plausibility of LES's proposed private disposal options, and to financial assurance — issues which remain before the Board.

### Emerging health risks

Despite the still somewhat limited amount of available data, the pattern of health risks of depleted uranium that is emerging begs caution in managing and disposing of DU. Recent research on the health effects of DU, much of it performed at the Armed Forces Radiobiology Research Institute after the 1991 Persian Gulf War, indicates that depleted ura-

**TABLE 3: SUMMARY OF IEER DOSE CALCULATIONS FOR SHALLOW EARTH DISPOSAL OF DU<sub>3</sub>O<sub>8</sub> POWDER**

Note that the doses are given in rem per year as opposed to millirem per year

U-238 Dose	U-235 Dose	U-234 Dose	Total Peak Dose (rem per year)	Regulation limit (rem per year)	Time at Peak Dose (years after emplacement)
32 to 658	14 to 47	81 to 200	141 to 795	0.025	9,807 to 17,412

Notes: The dose estimates are presented in ranges because they were calculated assuming a variety of scenarios, each using a unique combination of values for contaminant mobility, available moisture, and degree of erosion. All scenarios assume an arid climate. The annual doses for the uranium isotopes as shown include the contribution from their respective decay products as well. All numbers have been rounded.

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Uranium may be mutagenic, tumorigenic, teratogenic, cytotoxic, and neurotoxic. That is, it may cause or contribute to genetic mutations, tumors, birth defects, cellular level toxicity, and neurological damage. Uranium may also damage developing bones and cross the placenta and harm the embryo/fetus.

The new research indicates that in addition to its impact on the skeleton, on reproductive success, and on cancer induction and/or promotion, uranium may also be functioning analogous to a kind of radioactive lead in relation to its neurological impacts. In many of these areas there is also some indication of the potential for the heavy metal damage and the radiation-induced damage to be interacting in a synergistic manner. For more information, see the accompanying article on page 1.

New data and understanding about uranium's health effects are emerging in areas where little attention has been paid before. This research is likely to play an important role in shaping future risk assessments of DU. It is plausible that far stricter requirements for the disposal of DU will need to be adopted in the event that uranium is found to be more dangerous than currently believed, and particularly if children's health is to be protected in that event. After all, from time to time over the past several decades, standards governing the nuclear industry have been updated to reflect current understanding of risks.

The enrichment plant that LES proposes to build will generate significant quantities of DU over the coming decades which will also likely be a time of rapid and significant expansion in the understanding of uranium and its various health effects, both in isolation and in combination with other environmental stressors. In this context, LES and the NRC, which is legally charged with protecting the public health, must pursue a management and disposal strategy that will have a high probability of doing just that. They must be prepared to modify and adapt their plans in the event that radiation risks in general and uranium risks in particular are found to be greater than previously considered and to undertake provisions to specifically protect both women's and children's health. The NRC's DEIS is seriously deficient in not having mentioned the existing evidence pointing to such health risks, let alone evaluating them in the context of DU management and disposal. The inclusion of a specific cost contingency is one necessary component of building in this flexibility.

The NRC must take into account the expanding range of the health risks indicated by current research, especially as they are far more varied than health risks

*Data-free analysis ought to be unacceptable in any forum, but it is especially so in an environmental impact statement prepared by a government agency charged with protecting public health and safety.*

as presently estimated. Otherwise children in the future may be saddled with a legacy similar to that of the sorry history of lead poisoning over the past three generations, but this time with a heavy metal that is also radioactive. The potential for deleterious effects of depleted uranium needs to be considered by LES and the NRC before the decision is made to produce such large quantities of depleted uranium that will add to the management problems of the DU waste that has already been created.

### Costs of DU disposal

The choice of disposal strategy will have a significant impact on the choice of which deconversion process is to be pursued. There are at least two forms into which to deconvert  $\text{DUF}_6$  —  $\text{DUO}_2$  or  $\text{DU}_3\text{O}_8$ . The choice depends, in part, on the

method of disposal. IEER recommends a ceramic waste form, which is more effective at locking up materials at the atomic scale. This drives our preference for a choice of  $\text{DUO}_2$ .

We have concluded that neither disposal option as stated in the DEIS — the use of the DOE facilities or the construction of a private deconversion plant — can be considered a plausible strategy for the disposition of the depleted uranium tails that would result from operation of the proposed enrichment facility. We developed three alternate deconversion and disposal scenarios that we conclude to be more reasonable options. The three scenarios that we propose are:

1. The  $\text{DUF}_6$  is converted to  $\text{DUO}_2$ , grouted in cement, and then disposed of in a mine that is half the size of the mine considered for the depleted uranium in the DOE stockpile. The hydrofluoric acid generated would be neutralized into calcium fluoride ( $\text{CaF}_2$ ) which would then be disposed of as low-level waste at an appropriate site.
2. The  $\text{DUF}_6$  is converted to  $\text{DUO}_2$ , put into a ceramic type of waste form, and then disposed of in a deep geologic repository similar to the Waste Isolation Pilot Plant (WIPP) in New Mexico. As in Case 1, the hydrofluoric acid generated would be neutralized into  $\text{CaF}_2$  which would then be disposed of as low-level waste at an appropriate site. This case also includes a contingency for the added costs that should be prepared for in light of the evidence of potential risks of depleted uranium emerging for recent research.
3. A variation of Case 2 above with different assumptions regarding the costs of  $\text{CaF}_2$  storage and disposal as well as about the costs of operating the deep geologic disposal site.

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**TABLE 4: SUMMARY OF THE ASSUMPTIONS FOR THE THREE IEER SCENARIOS FOR DU MANAGEMENT AND DISPOSAL**

Scenario	Deconversion assumptions	Disposal assumptions	Financial assumptions	Contingency due to uranium risk	Comments	Cost per kilogram uranium
Case 1: grouted DU	UO <sub>2</sub> , grouted	Deep mine	10 percent exchange rate risk for deconversion	None	UO <sub>2</sub> deconversion costs higher but disposal costs lower, and overall disposal costs lower	\$13.59
Case 2: GTCC, WIPP	UO <sub>2</sub> , ceramic waste form	Equivalent to WIPP	30 percent exchange rate risk for deconversion	19 percent increase in deconversion and disposal cost items	Low end of WIPP cost projections, low ceramic costs, U risk corresponds to increased risk to females	\$23.79
Case 3: GTCC, WIPP	UO <sub>2</sub> , ceramic waste form	Equivalent to WIPP	30 percent exchange rate risk for deconversion	19 percent increase in deconversion and disposal cost items	Medium estimate of WIPP cost projections, low ceramic costs, U risk corresponds to increased risk to females	\$30.41

Note: Total DUF<sub>6</sub> expected to be generated is 197,000 metric tons, equivalent to about 133,000 metric tons of elemental uranium. For additional notes and references to this table see pages 48 and 51 of the IEER report on LES.

We estimated costs for deconverting and disposing of DU under the three scenarios. The assumptions and cost estimates are shown in Table 4. In all the scenarios, a 25 percent contingency for unforeseen circumstances is included. IEER’s estimates of reasonable costs for DU disposal for the purposes of licensing are represented by Cases 2 and 3, which assume disposal of DU on a basis similar to WIPP, whatever its waste classification might be. The notation of the scenarios as GTCC simply refers to the physical and radiological properties of DU and its associated health risks.

These estimated costs translate into a cost of between \$3 billion and \$4 billion to properly manage and dispose of the depleted uranium waste generated by the uranium enrichment plant proposed to be built in New Mexico. Costs corresponding to any of the three scenarios would likely make the proposed plant uneconomical, increasing the likelihood of default on deconversion and disposal obligations. Such high costs could not be recovered from the customers for enrichment services. This makes it imperative that financial guarantees are required to be posted up front as part of the conditions imposed for granting a license. In its July 2004 license application, LES proposed to put aside just \$731 million to cover the cost of managing its DU tails.<sup>15</sup>

A license based on the premise that LES could recover anything like the costs of DU disposal elaborated here (and they are not the highest reasonable cost estimates that could be made) would run a considerable risk of saddling U.S. taxpayers and future generations with the immense liabilities of DU management and disposal. An encashable financial guarantee up front of at least

\$2.5 billion (present value), appropriately escalated — that is, not dependent on the financial health of the proposed enrichment plant or its sales — is essential to protect the people of New Mexico, U.S. taxpayers, and future generations from the liabilities associated with the DU that the proposed LES uranium enrichment plant would generate. ■■

- 1 A number of factors have hampered the production of this report. First, the NRC imposed a requirement of completing the report in an unreasonably short period of time (one month). Second, the report was prepared in the absence of full disclosure by LES of the state of information and negotiations about the expected costs of depleted uranium (DU) deconversion. Third, the NRC failed to provide the basis for its dose calculations of the impacts of DU disposal. Fourth, the NRC’s public database (ADAMS, the Agency-wide Documents Access and Management System) was largely unavailable due to an ongoing security review which prevented us from gaining access to potentially important information. IEER has reserved the right to update and revise the report.
- 2 For more information about the uranium enrichment process, related technology and global status, see *Science for Democratic Action* vol. 13 no. 1, March 2005, on the web at [www.ieer.org/sdfiles/13-1.pdf](http://www.ieer.org/sdfiles/13-1.pdf).
- 3 DU can be converted to plutonium-239 in nuclear reactors, and this was at one time thought to be the major potential use of DU. However, commercial use of plutonium is, in fact, very limited and the use of DU in this application is negligible compared to the amounts of depleted uranium that have been created over the past six decades.
- 4 U.S. Nuclear Regulatory Commission. *In the Matter of Louisiana Energy Services, L.P. (National Enrichment Facility)*. Docket No. 70-3103-ML. Memorandum and order. CLI-05-05. Docketed and served 1/18/05. p. 26. On the Web at [www.nrc.gov/reading-rm/doc-collections/commission/orders/2005/2005-05cli.html](http://www.nrc.gov/reading-rm/doc-collections/commission/orders/2005/2005-05cli.html).

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## COSTS

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- 5 Under 10 CFR 55(a).
- 6 National Research Council. Board on Radioactive Waste Management. Committee on Improving the Scientific Basis for Managing Nuclear Materials and Spent Nuclear Fuel through the Environmental Management Science Program. *Improving the Scientific Basis for Managing DOE's Excess Nuclear Materials and Spent Nuclear Fuel*. Washington, DC: National Academies Press, 2003. Page. 67. On the Web at <http://books.nap.edu/books/0309087228/html/index.html>.
- 7 10 CFR 61.
- 8 For safety reasons, it is generally agreed that depleted uranium hexafluoride (DUF<sub>6</sub>) must eventually be "deconverted" from its reactive form to a final waste form, either depleted uranium dioxide (DUO<sub>2</sub>) or depleted uranium oxide (DU<sub>3</sub>O<sub>8</sub>) for long-term management or disposal. Both NRC and DOE claim that DUF<sub>6</sub> is safe to store for long periods of time.
- 9 The DOE is obligated to accept the DU from enrichment plants under the USEC Privatization Act (42 U.S.C. 2297h-10) as amended. The price that the DOE can charge for this service in the future is not currently set. However, previous versions of the energy bills considered by the House and Senate would have limited the price the DOE could charge to as little as 71 to 90 cents per kilogram of DU. The Energy Policy Act of 2005, recently passed by the House (H.R. 6, passed April 21, 2005), removed this provision. No Senate version of the energy bill for 2005 has yet been proposed.
- 10 U.S. Nuclear Regulatory Commission. Office of Nuclear Material Safety and Safeguards. Division of Waste Management and Environmental Protection. *Environmental Impact Statement for the Proposed National Enrichment Facility in Lea County, New Mexico: Draft Report for Comment*. NUREG-1790. Washington, DC, September 2004. On the Web at [www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1790/](http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1790/).
- 11 Even under court order, the DOE violated its legal obligation to take spent fuel from nuclear power plants starting in January 1998 and now projects that the earliest the waste could be accepted would be the end of 2012.
- 12 Assuming a density of 3 gm/cm<sup>3</sup>, the volume of the DU<sub>3</sub>O<sub>8</sub> powder that was proposed for disposal in the CEC case would have alone totaled approximately 20,000 m<sup>3</sup>. (NRC CEC FEIS 1994 p. A-1, A-7)
- 13 For reference, the Great Lakes system contains approximately 23,000 km<sup>3</sup> of water, accounting for roughly 18% of the entire world's supply of fresh surface water. (EPA Great Lakes Atlas)
- 14 Over the very long timescales that must be considered for the disposal of depleted uranium, the impacts of natural and potentially anthropogenic climate change need to be considered in determining the land use scenario and meteorological parameters appropriate for dose modeling. Although it is outside the scope of the present report, this consideration argues for the use of the resident farmer scenario as part of this type of generic screening analyses.
- 15 Louisiana Energy Services. *National Enrichment Facility Safety Analysis Report*. Rev. 2. [Albuquerque, NM?], July 2004. On the Web at [www.nrc.gov/materials/fuel-cycle-fac/ml043540004.pdf](http://www.nrc.gov/materials/fuel-cycle-fac/ml043540004.pdf). p. 10.3-3.

## HEALTH RISKS

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from uranium. For depleted uranium, the drinking water limit translates into about 12 pCi/L of uranium activity. Federal regulations limit uranium inhalation based on cancer risk and limit drinking water intake based mainly on kidney toxicity.

Exposure to uranium in water is regulated for chemical toxicity largely because uranium is known to be nephrotoxic (toxic to the kidneys). The kidneys are responsible for controlling the composition of blood and eliminating wastes. Important uncertainties remain as to the level of sensitivity of human kidneys to depleted uranium. Animal studies have shown toxic thresholds that differ by more than an order of magnitude between experiments on rabbits (more sensitive) and rats (less sensitive).

The science surrounding uranium's effects on the body is rapidly expanding due in large part to the concerns that have arisen in the wake of the 1991 Gulf War, the 1999 NATO bombing campaign in the former Yugoslavia, and the gradual recognition of the many health problems that have come to be known as Gulf War Syndrome. We discuss below the emerging picture from this research.

### Ionizing radiation risks

Ionizing radiation is a known carcinogen; as such, exposure to it increases the risk of a variety of cancer types. The current best understanding of low-dose radiation effects, and that which forms the basis of regulatory practice in the United States and Europe, is that every increment of radiation exposure produces an incremental increase in the risk of cancer. This is known as the linear no-threshold hypothesis.<sup>2</sup>

In general, the estimated risks per unit of exposure have increased with time as more is learned about the interaction of radiation with living tissue. As a result, the maximum permissible doses have been decreased. For example, in 1954 the AEC set the radiation limit at 15 rem per year.<sup>3</sup> This was a significant reduction from the 0.1 roentgen per day limit that had been adopted in 1942 during the Manhattan Project. In 1959, the dose limit for the public was lowered to 0.5 rem per year and was then lowered again in 1990 to 0.1 rem per year.<sup>4</sup>

The *non-cancer* effects discussed below (other than kidney toxicity) are indicated by laboratory research, which is often done at elevated levels of exposure. These effects have not been definitively established for human beings in terms of quantitative health risks. Also, some of the experiments we cite were conducted with uranium directly injected into animals or with depleted uranium in metallic form embedded under the skin, which are pathways different than what would

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## HEALTH RISKS

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be expected from environmental exposures from the disposal of depleted uranium oxide. Also, it has not been established whether some non-cancer effects have thresholds, in contrast to the well-accepted no-threshold hypothesis for cancer risk of ionizing radiation.

An additional element of radiological protection that has evolved over time is the understanding of the relative risks to women and men. Currently, the overall risk to women of developing a fatal cancer from exposure to low-dose, low-LET (Linear Energy Transfer) radiation is estimated to be nearly 50 percent greater than that for men. Nearly 45 percent of the additional risk to women per unit of exposure is due to the significant radiosensitivity of the female breast.<sup>5</sup> If cancer *incidence* is considered, irrespective of fatality, the comparison is grows slightly worse, with women having more than a 58 percent greater risk of developing some form of cancer from radiation exposure than men.

### Current research on DU

The understanding of the risks of cancer due to radiation exposure from depleted uranium and of kidney damage due to its heavy metal properties has expanded greatly in recent years. In addition, evidence is amassing that raises serious concerns regarding the impact of chronic exposure to DU in relation to a number of other health issues. Studies in humans and animals have shown that uranium can concentrate to varying degrees in the skeleton, liver, kidneys, testes, and brain. In addition, rats implanted with DU pellets have shown uranium concentrating in the heart, lung tissue, ovaries, and lymph nodes among other tissues.

As noted above, some research has also provided indi-

cations that there may be a synergistic effect between the heavy metal aspect of exposure to uranium and its radioactive effects. Research on the hazards of the heavy metal cadmium indicated a potential synergistic response when exposures were combined with gamma radiation. Work on these kinds of combined exposures has shown that the direct damage to DNA from radiation exposure was likely combined with an inhibition of DNA repair by certain heavy metals. A double whammy, so to speak.

Research at the Armed Forces Radiobiology Research Institute (AFRRI) in Bethesda, Maryland has shown that depleted uranium can cause oxidative DNA damage and thus provides the first indication that uranium's radiological and chemical affects might potentially play both a tumor-initiating and a tumor-promoting role. We will discuss some of these potential aspects of depleted uranium's health effects that are emerging from a wide range of research.

### Mutagenic and tumorigenic effects

Since the late 1990s there has been a growing body of evidence from in vitro and in vivo studies that indicates depleted uranium may be genotoxic, mutagenic, and tumorigenic. A significant amount of this work is currently being conducted at the AFRRI under the direction of Dr. Alexandra Miller.

Miller and her colleagues demonstrated for the first time that internalized depleted uranium could result in "a significant enhancement of urinary mutagenicity," a common biomarker of exposure to a genotoxic agent.<sup>6</sup> They also demonstrated for the first time that exposure to DU can transform human cells into cells capable of producing cancerous tumors in mice with suppressed immune systems. They found that exposures to equal chemical concentrations of uranium with different isotopic composition caused "a specific activity dependent increase in neoplastic transformation frequency" which further suggested "that radiation can play a role in DU-induced biological effects in vitro."

Miller *et al.* also found in other experiments that DU was capable of inducing "oxidative DNA damage in the absence of significant radioactive decay." In light of their other work showing the potential for the radiological aspect of DU to contribute to genotoxic effects in vitro, they note that "it is tempting to speculate that DU might exhibit both a tumor 'initiation' and 'promotion' component." This potential dual role could result from, for example, the alpha particle radiation causing the cancerous mutation (tumor initiation) followed by a build up of oxidative damage from either or both the heavy metal and radiation properties of uranium aiding the spread of the cancer (tumor promotion), or vice versa.

The relative role of the radiological and chemical

## DEFINITIONS

**Cytotoxic:** Toxic to cells.

**Genomic instability:** An increased tendency of DNA to not repair itself correctly, typical of cancer cells.

**Genotoxic:** Damaging to DNA.

**In vitro:** experiments conducted outside the body.

**In vivo:** experiments conducted inside the body.

**Micronuclei:** Chromosome fragments that are not incorporated into the nucleus at cell division.

**Mutagenic:** Causing or contributing to inheritable genetic mutations.

**Neoplastic transformation:** The conversion of normal cells into tumor cells.

**Progeny:** Offspring.

**Tumorigenic:** Tumor-causing.

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## HEALTH RISKS

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components of the genetic damage caused by the depleted uranium is a significant question given that DU is currently regulated for drinking water with a primary focus on its chemical hazard with the implicit assumption that its radiation hazard can generally be treated as a secondary concern in the environment.

A final example of the work being conducted at the AFRRRI on these issues comes from a 2003 Miller *et al.* publication concerning the potential for DU to induce genomic instability in human cells. It is worth noting here that DU emits alpha particles during radioactive decay. In this work the authors initially note that:

Studies with DU in our laboratory demonstrated neoplastic transformation of human cells under conditions where approximately 14% of the DU-exposed cells were transformed even though less than 5% were traversed by an alpha particle. These findings suggest that factors other than direct or “targeted” damage to the DNA may be involved in the transformations. Chemical effects of DU and “non-targeted” effects of radiation may also play a role. Non-targeted effects can result in damage in cells not traversed by an alpha particle. The overall level of transformation observed may result from contributions by any or all of these factors.

In order to gauge the impact of radiation and heavy metal toxicity separately, the effects of depleted uranium were compared to that of nickel (Ni) and to gamma irradiation. From the results of their experiments, Miller *et al.* concluded:

In summary, we have presented data showing the production of genomic instability in the progeny of human cells exposed to DU. The findings demonstrate that DU can induce delayed cell death and genetic alterations in the form of micronuclei. Compared to gamma radiation or Ni, DU exposure resulted in a greater manifestation of genomic instability. Although animal studies are needed to address the effect of protracted DU exposure and genomic instability in vivo, results obtained from our in vitro system can play a significant role in determining risk estimates of DU exposure.

### *Effects on children and the embryo/fetus*

Children as well as the embryo/fetus are likely to be at higher risk in relation to the mutagenic and carcinogenic nature of uranium. The International Commission on Radiological Protection (ICRP) notes that:

It is very well known that ionising radiation interferes to a high degree with cell proliferation. Therefore, biological systems with a high fraction of proliferating cells show high radiation responsiveness. High rates of cell proliferation are found throughout prenatal development. However,

although cell proliferation is a key process for the development of radiation effects, the sensitivity of the embryo and fetus is also determined through processes of differentiation and cell migration, and the radiation effects on these biological processes.

...

Tissues such as brain, thyroid, bone, and breast appear to be more susceptible if exposed during normal periods of rapid growth (i.e. early childhood or puberty).<sup>7</sup>

Acknowledging these larger risks to children from radiation exposure, the 2002 supplement to the U.S. Environmental Protection Agency’s Federal Guidance Report 13 introduced mortality and morbidity coefficients per becquerel of intake for various age groups including 0 to 5 years old. For the three uranium isotopes present in DU, the risk of developing a fatal cancer per unit of intake for a child under five is roughly six to eight times greater than the age-averaged risk currently used by the EPA for dietary and drinking water intake respectively.

Taken together, these considerations — increased risk per unit of intake combined with the unique exposure pathways for children to environmental contaminants such as DU, and the fact that uranium is known to be capable of crossing the placental barrier and concentrating in the embryo/fetus — make it plausible that far stricter requirements for the disposal of DU will need to be adopted in the event that uranium is concluded to be more carcinogenic than currently believed, and particularly if children’s health is to be protected in that event.

### *Reproductive effects*

Investigations of the reproductive effects of uranium exposure in animals were reported as far back as the 1940s, however, these early studies do not appear to have been systematically followed up on by other researchers in the United States until many decades later. Even today, there are substantial gaps in the understanding of uranium’s effects on human and animal reproduction.

In the 1940s experiments, it was found that continuous feeding or even just a single one time feeding of uranium to rats could detrimentally affect the animal’s reproductive success. The impact of continuous feeding was significantly greater than that of the one time ingestion, but the authors noted their surprise at finding an impact on the rat’s reproductive success even 9 months after a single exposure to uranium.<sup>8</sup>

Why these provocative early studies do not appear to have been carried forward or more widely reported is

Children as well as the embryo/fetus are likely to be at higher risk in relation to the mutagenic and carcinogenic nature of uranium.

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not clear. However, the work that has been done recently on uranium has expanded these early findings and has resulted in the identification of two distinct areas of concern in regard to the potential impact of uranium on reproductive health. The first area relates to the risks associated with exposures of men while the second relates to exposures of women.

Uranium is found to concentrate in the testes and has been found in the sperm of Gulf War veterans at elevated levels. While no epidemiological data yet demonstrates an impact on reproductive success from the veteran's exposure, the Royal Society (of Britain) noted that the concentration of DU in the testes was a potential concern given the possible synergistic effects between uranium's ability to damage DNA through both chemical oxidative stress and ionizing alpha radiation. In addition, the World Health Organization has noted the observation of "unspecified degenerative changes in the testes" of rats as a result of chronic ingestion of soluble uranium compounds.

Although still very limited, somewhat more work has been done on the reproductive effects of uranium exposure on females. Uranium has been shown to cross the placental barrier and concentrate in fetal tissue. Experiments with animals have demonstrated that exposure to uranium either through ingestion or injection can cause "[d]ecreased fertility, embryo/fetal toxicity including teratogenicity, and reduced growth of the offspring." These findings have been demonstrated in both rats and mice, and provide evidence (at least at the levels of uranium ingestion examined) that uranium exposure can adversely affect the reproductive success of females. The one reported experiment to use depleted uranium did not find statistically significant effects on "maternal weight gain, food and water intake, time-to-pregnancy, or the percentage of litters carried to terms," however, higher numbers of implanted DU pellets were found to lead to increasing concentrations of uranium in the placenta and whole fetus of rodents.

While there are still many unknowns as to the effects of uranium on reproductive success, a number of potential radiological and non-radiological mechanisms have been proposed to help explain the effects that have been observed. These proposed mechanisms include hormonal or enzymatic disruption and behavioral changes. In addition, we have already noted the ICRP's conclusions regarding the greater general radiosensitivity of the developing embryo/fetus as well as of young children which may also play a potential role in DU's effects on reproductive success.

Uranium has been shown to cross the placental barrier and concentrate in fetal tissue.

## Neurotoxic effects

Limited evidence linking uranium to neurological damage dates back to at least the mid-1980's. While these early reports have a number of problems that have hampered their usefulness in drawing solid inferences regarding the neurological risks of depleted uranium, they provided an impetus for further research. Research that started in the 1990s began to raise new concerns about the potential toxic effects of DU on the brain.

One of the major concerns connected to this recent work centers around the fact that uranium's primary chemical form in the body is the uranyl cation ( $\text{UO}_2^{2+}$ ) which is a toxic heavy metal chemically analogous to the lead cation ( $\text{Pb}^{2+}$ ) which has a well-documented and tragic history as a neurotoxin and is a particular concern in relation to children's health.

In 1999 Pellmar *et al.* at the AFRRRI showed that depleted uranium implanted in mice concentrated in various regions of the brain with higher concentrations at higher levels of exposures. From these results they concluded that "[t]he accumulation in brain, lymph nodes, and testicles suggest the potential for unanticipated physiological consequences of exposure to uranium through this route."<sup>9</sup>

In additional research, Pellmar *et al.* were able to further show that the "exposure to DU fragments caused neurophysiological changes in the hippocampus." The hippocampus was chosen for analysis because it is the region of the brain involved in memory and learning. Reviews of these AFRRRI experiments have concluded that their results provide important evidence of the potential for depleted uranium to display neurotoxic effects.

Other researchers have shown that following ingestion, uranium concentrated in the brains of mice and of rats. Some of the experiments in mice have shown effects on the brain with potential neurotoxicological importance at levels of uranium exposure that were not found to cause discernable damage to the kidneys. A recent study found observable behavioral changes in rats after 2 weeks exposure to DU in drinking water.<sup>10</sup>

A specialized computer test designed to assess "performance efficiency" has been used to look for potential neurological effects in veterans who were exposed to depleted uranium munitions during the Gulf War. These tests, conducted at the Baltimore VA Medical Center, observed a statistically significant correlation between uranium concentration in the veteran's urine and poorer performance on the computerized neurocognitive tests. However, no measurable effects were found in this same group using traditional neurocognitive tests. It is important to recall in this case that the soldiers were exposed as adults, and that these tests do not provide information

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on the impacts of uranium exposures during the more sensitive stages of early childhood when the brain is undergoing rapid growth and development or when the blood-brain barrier is not yet fully formed.

In addition to the potential for uranium to play a chemically neurotoxic role analogous to lead, radiation is also known to adversely affect the nervous system of the embryo/fetus. From a review of the Japanese atomic bomb survivor data, the ICRP, in the same publication referenced earlier, concluded:

There is a clear constellation of effects of prenatal irradiation on the developing central nervous system – mental retardation, decreased intelligence scores and school performance, and seizure disorders.

The ICRP elaborated further on why the prenatal period is of particular concern for radiation damage to the nervous system and why it is so important to consider in assessing risks:

Development of the central nervous system starts during the first weeks of embryonic development and continues through the early postnatal period. Thus development of the central nervous system occurs over a very long period, during which it is especially vulnerable. It has been found that the development of this system is very frequently disturbed by ionising radiation, so special emphasis has to be given to these biological processes.

Prenatal exposures to lead and mercury have also shown an indication that they are capable of doing neurological damage during this period of rapid development. However, the early years of childhood are generally considered to be the most critical time period for exposure to heavy metals given babies' greater potential for environmental exposures. As with a number of other emerging risks discussed above, there is also the potential for synergisms between uranium's chemical and radiological effects on the nervous system.

It is important to note that even relatively small changes in average IQ, spread over a large number of children, will "dramatically increase the proportion of children below any fixed level of concern, such as an IQ of 80, and decrease the proportion above any 'gifted' level, such as 120." Thus the effect of neurotoxic agents, even at very low levels, on an exposed population as a whole can end up being quite significant even if the effect on an "average" or "typical" member of that population does not appear so.

### Skeletal effects

As with the brain, the fetal period and other periods of rapid development (i.e. in early childhood and during puberty) are times of heightened sensitivity for the skeletal.

eton. In experiments on rats, it has been demonstrated that both acute and chronic intakes of uranium can cause damage to bones, and the Royal Society has recommended that, in light of the fact that uranium crosses the placental barrier, "the effects of maternal exposure to DU on skeletal development in the foetus may also need to be considered." The World Health Organization and the National Research Council have also recommended studies to determine what effect, if any, uranium integrated into the bone has on the bone marrow and thus on the production of new blood cells. A new study that exposed dogs to daily doses of uranyl nitrate from a young age found that uranium accumulated in the marrow as much as in the bone, contrary to results obtained with single, acute doses.<sup>11</sup>

### Uranium: Radioactive lead?

There are clear indications that uranium toxicity for at least some effects, including its neurotoxic effects on fetuses and young children, might be better understood if uranium was considered to be analogous to a kind of radioactive lead, in which the damage from the alpha radiation occurs in conjunction with heavy metal induced damage to produce a variety of health problems at relatively low levels of exposure. This analogy between uranium and lead was made in 2003 by Lemerrier *et al.* in reporting their study demonstrating the concentration of uranium in the brain of rats.<sup>12</sup> While this way of thinking has obvious limitations in regards to understanding the detailed biological mechanisms involved in the damage caused by uranium as compared to lead, the ability of uranium to chemically induced oxidative stress, to cross the blood-brain barrier and alter electrical activity in parts of the higher brain, and to potentially interrupt neurotransmitters through chemical replacement of calcium in the interneuron gaps all in combination with the high levels of local cellular damage caused by alpha radiation raises significant warning signs about the potential impact of uranium on a child's developing brain.

In light of the uranium-lead analogy, it should be noted that despite evidence of lead's damaging effect on the brain dating back nearly two millennia and lead poisoning being first clinically recognized in children as early as the 1890's, it was not until 1979 that leaded gasoline was finally taken off the U.S. market after being widely sold for several decades. As with the general trend in radiation protection standards, the Centers for Disease Control (CDC) has chosen to lower the guideline it considers to be an indicator of "elevated" levels of lead in the blood of children four times since the late 1960s. The level today is one-sixth of where it stood 35 years ago. In addition, the

The prenatal period is of particular concern for radiation damage to the nervous system

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## It pays to increase your jargon power with Dr. Egghead

### Alpha particle

- The very first unit of matter as discovered by the Greek scientist-philosopher Physicles.
- The dominant particle to which other particles show deference through ritualized gestures such as bowing and allowing the alpha to be emitted first.
- The nucleus of a helium-4 atom (with two neutrons and two protons) that is discharged by radioactive decay of many heavy elements, such as uranium-238 and plutonium-239.

### Becquerel

- The male counterpart of the Becquerelle.
- A quarrelsome person. *The becquerel was always bickering with us.*
- A unit of radioactivity equal to one disintegration of a nucleus per second, equal to about 27 picocuries.

### Biomarker

- The scent left by a dog marking its territory.
- Bookstore slang for a bookmark specially designed for biographies.
- A specific biological feature that can be measured — for instance, the level of a substance in the blood, the presence of a gene mutation, or a change in a biological process — to indicate a disease or condition.

### DUF<sub>6</sub>

- D.U.F. = Daily Use of Folly. DUF<sub>6</sub> describes a person who is foolish six times per day.
- Gym bag for giants. More specifically, a duffle bag 6 times the average size.
- Depleted uranium hexafluoride, a product of the uranium enrichment process. DUF<sub>6</sub> is a chemical form of uranium that has been “depleted” of the uranium-235 isotope.

### LET

- Linear Egghead Transfer, the Amtrak train that takes Arjun from Washington to New York and back.
- Lucky Espionage Theory, the theory that spies stumble upon intelligence by chance.
- Linear Energy Transfer, the average amount of energy transferred by radiation into the surrounding medium per unit length of the medium. For example, alpha radiation is high-LET radiation because it transfers energy into cells (or water or other materials) at a high rate per unit distance; photons and electrons are low-LET radiation.

### Rad

- What the Becquerel says when it sees a Becquerelle.
- Royal Academy of Dumplings, the largest and most influential organization in the world dedicated to the preparation and promotion of steamed and seasoned dough balls.
- Radiation absorbed dose, a unit of absorbed dose of radiation defined as deposition of 100 ergs of energy per gram of tissue.

### Rem

- A male sheep.
- Rapid Ear Movement.
- A unit of equivalent absorbed dose of radiation, taking into account the relative biological effectiveness (RBE, the relative capability of the different radiation types — alpha particles, X-rays, etc. — to cause biological damage). The dose in rems is the dose in rads multiplied by the RBE.

### Roentgen

- The name of a German rent-a-gene company.
- Unit of ionizing radiation lethal to rodents weighing one kilogram. Named for the 19th century chemist Markus Roentgen whose pet hamster was accidentally killed by radiation exposure when she sneaked into his laboratory.
- A unit of gamma radiation measured by the amount of ionization in air. In non-bony biological tissue, one roentgen delivers a dose approximately equal to one rad.

### Secular equilibrium

- In transcendental meditation, the time at which everyone in the world is thinking exactly the same thing.
- When the total weight of all religious people worldwide is equal to that of all non-religious people worldwide.
- The point at which the activity of the decay product (daughter nuclide) equals the activity of the parent. In other words, when equal numbers of atoms of all members of the decay series disintegrate at the same rate.

### Synergism

- Discrimination against synergies.
- A system of belief that Syn, the Norse goddess of watchfulness and truth, controls all the universe's energy.
- Combined activity such that the effect is either equal to or greater than the sum of the separate effects.

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## DR. EGGHEAD

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### UO<sub>2</sub>

- a. Slang for “you owe me two dollars.”
- b. A very popular rock band whose lead singer almost became president of the World Bank.
- c. Uranium dioxide, one of the chemical forms into which to DUF6 can be changed prior to disposal. Unlike U<sub>3</sub>O<sub>8</sub> (see below), UO<sub>2</sub>, with its smaller and more uniform particle size, can be put in a ceramic waste form that is more suitable for long-term management.

### U<sub>3</sub>O<sub>8</sub>

- a. Slang for group debt: You three owe me eight dollars.
- b. New generation of UFOs that will use the new reactors being secretly designed in Idaho.
- c. Uranium oxide, one of the chemical forms into which to DUF<sub>6</sub> can be changed prior to disposal.

Match up each of the following 5 terms with its correct definition:

- |                |                                                                               |
|----------------|-------------------------------------------------------------------------------|
| 1. Cytotoxic   | a. Causing or contributing to genetic mutations.                              |
| 2. Mutagenic   | b. Toxic to cells.                                                            |
| 3. Neurotoxic  | c. Toxic specifically to hair follicles.                                      |
| 4. Teratogenic | d. Tumor-causing.                                                             |
| 5. Tumorigenic | e. Causing abnormal development of the embryo, i.e. birth defects.            |
|                | f. Promoting ovulation.                                                       |
|                | g. Damaging to the nervous system, including the brain and other nerve cells. |

Answers: 1. b, 2. a, 3. c, 4. e, 5. d.

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CDC has adopted the position that there is no safe level of exposure to lead, and that any intake will thus result in some level of harm.

Unfortunately, despite significant reductions in exposure since 1979, the current levels of lead in children's blood are still roughly 100 to 1,000 times larger than the estimated pre-industrial levels, and as of the year 2000 the CDC estimated that nearly half a million children in the U.S. still exceeded their guideline for elevated levels of lead in the blood. Adding to these concerns, continuing research on the effects of lead shows that children's intellectual function is adversely affected by exposures roughly half of the CDC/WHO level of concern, further supporting the conclusion that there is likely no threshold for lead's damaging effects.

In addition to lead's neurotoxicity, recent research has also shown that both prenatal and postnatal exposure to lead is associated with retarded growth in animals and humans and that exposure to lead can also alter sex hormone production and delay puberty in rats. An epidemiological study published in 2003 has shown that even relatively low average levels of lead (roughly a third of the CDC/WHO level of concern) caused a measurable delay in puberty in African-American and Mexican-American girls, while no statistically significant delay in Caucasian girls was found. This effect on the girl's sexual development was attributed, at least in part, to potential “alterations in endocrine function.” Many questions as to how lead caused the observed delay and whether or not the children had been exposed to higher levels in the past, before the study's screening began, remain unanswered. Nevertheless, the potential for uranium to play an analogous role in effecting hormonally-mediated processes in developing children could add further to its list of health concerns and add significant new avenues

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## HEALTH RISKS

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for potential synergisms with its other chemical and radiological health effects.

The lessons of lead's tragic history in relation to children's health — including the decades-long denial of the risks by industries producing lead-based products, as well as the systematic and progressive tightening of health guidelines specifically targeting children once the guidelines were finally introduced — should be closely examined in relation to the direction uranium research is now unfolding. ■■

- 1 This article is based on the IEER report, *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico* by LES, prepared for Nuclear Information and Resource Service (NIRS) and Public Citizen. Detailed references can be found in the report, which is available online at [www.ieer.org/reports/du/LESrptfeb05.pdf](http://www.ieer.org/reports/du/LESrptfeb05.pdf).
- 2 See National Council on Radiation Protection and Measurements. *Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation*. NCRP report no. 136. Bethesda, MD: June 4, 2001.
- 3 For a summary of historical annual regulatory dose limits for workers in the U.S., see SDA vol. 9 no. 1, December 2000, on the web at [www.ieer.org/sdfiles/vol\\_9/9-1/dosetbl.html](http://www.ieer.org/sdfiles/vol_9/9-1/dosetbl.html).
- 4 U.S. Dept. of Energy, Office of Environmental Safety and Health. *Radiation protection of the public and the environment*. Order: DOE 5400.5, Washington, DC: February 8, 1990. Section II.1.a.
- 5 The overall cancer risk per person-Gray of exposure to women from low-dose, low-LET uniform irradiation is estimated to be  $6.83 \times 10^{-2}$  while the risk to men is  $4.62 \times 10^{-2}$ . The female breast has the second highest risk per unit of exposure of any individual

organ listed for either men or women in this EPA guidance document and is higher than any individual organ risk for men. (Keith F. Eckerman, Richard W. Leggett, Christopher B. Nelson, Jerome S. Puskin, Allan C.B. Richardson. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides: Radionuclide-Specific Lifetime Radiogenic Cancer Risk Coefficients for the U.S. Population, Based on Age-Dependent Intake, Dosimetry, and Risk Models*. Federal Guidance Report No. 13. EPA 402-R-99-001. Oak Ridge, TN: Oak Ridge National Laboratory; Washington, DC: Office of Radiation and Indoor Air, United States Environmental Protection Agency, September 1999.)

- 6 Unless otherwise stated, this and the rest of the research referenced in this section refers to a number of papers by Miller *et al.* published between 1998 and 2003. For full references, see pages 10-13 of the IEER report on which this article is based, *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico* by LES, online at [www.ieer.org/reports/du/LESrptfeb05.pdf](http://www.ieer.org/reports/du/LESrptfeb05.pdf).
- 7 International Commission on Radiological Protection. *Biological effects after prenatal irradiation (embryo and fetus)*. Annals of the ICRP, v. 33, no. 1-2. ICRP publication 90. Kidlington, Oxford; Tarrytown, NY: Pergamon, 2003.
- 8 References for this section can be found on pp. 13-14 of IEER's report on LES.
- 9 Unless otherwise indicated, references for this section can be found on pp. 14-16 of the IEER LES report.
- 10 Wayne Briner and Jennifer Murray, "Effects of short-term and long-term depleted uranium exposure on open-field behavior and brain lipid oxidation in rats." *Neurotoxicology and Teratology*, v. 27 (2005). pp. 135-144.
- 11 Arrudo-Neto *et al.* "Long-term accumulation and microdistribution of uranium in the bone and marrow of beagle dog." *Int. J. Radiat. Biol.*, vol. 80, no. 8 (2004), pp. 567-575.
- 12 Lemercier, *et al.* "Study of uranium transfer across the blood-brain barrier." *Radiation protection dosimetry*, v. 105, nos. 1-4 (2003). pp. 243-245.

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