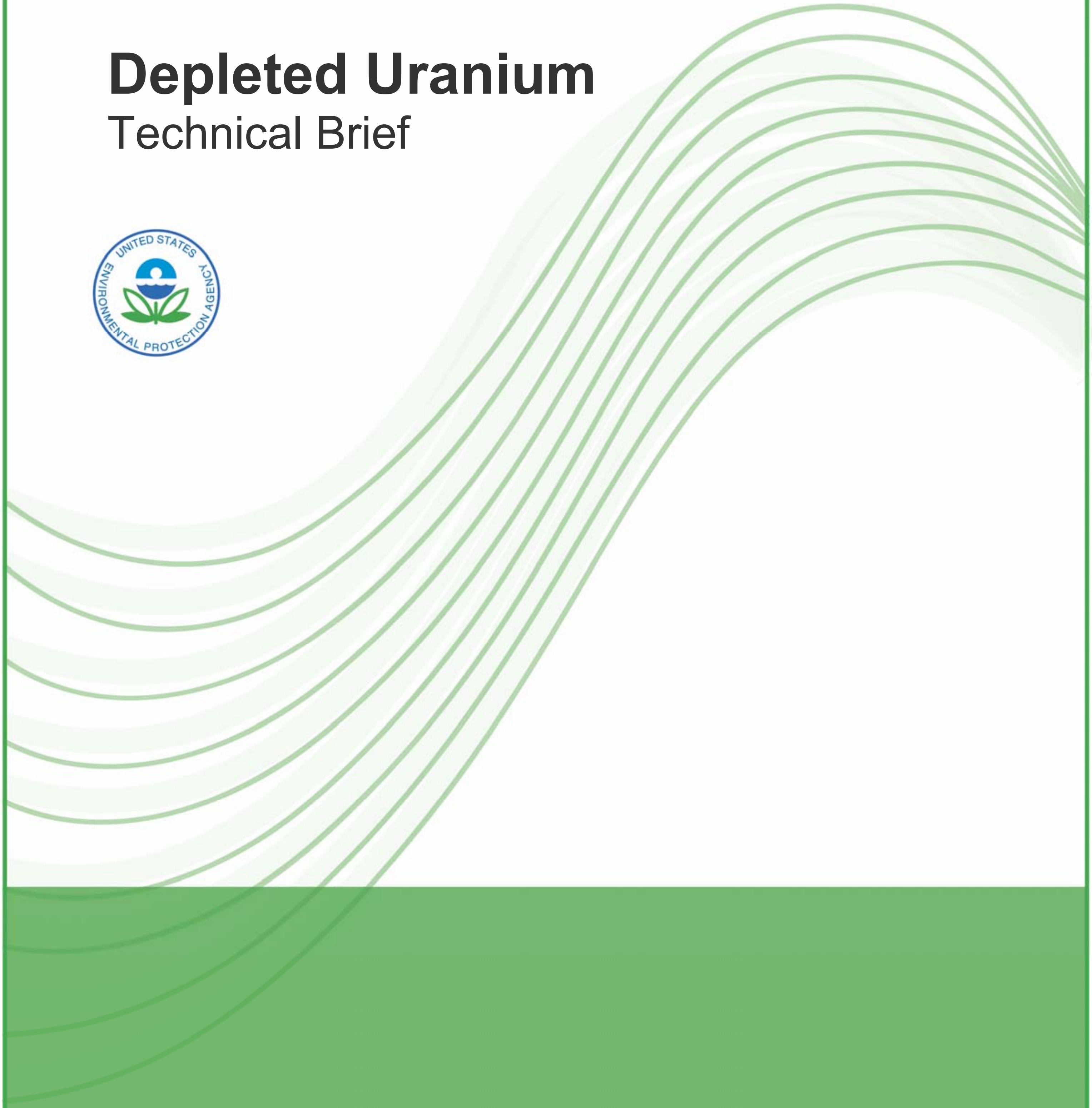
Depleted Uranium

Technical Brief



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FOREWARD

The Depleted Uranium Technical Brief is designed to convey available information and knowledge about depleted uranium to EPA Remedial Project Managers, On-Scene Coordinators, contractors, and other Agency managers involved with the remediation of sites contaminated with this material. It addresses relative questions regarding the chemical and radiological health concerns involved with depleted uranium in the environment.

This technical brief was developed to address the common misconception that depleted uranium represents only a radiological health hazard. It provides accepted data and references to additional sources for both the radiological and chemical characteristics, health risk as well as references for both the monitoring and measurement and applicable treatment techniques for depleted uranium.

Please Note: This document has been changed from the original publication dated December 2006. This version corrects references in Appendix 1 that improperly identified the content of Appendix 3 and Appendix 4. The document also clarifies the content of Appendix 4.

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1. PURPOSE

Technical Briefs are designed to convey available information and knowledge about a particular contaminant of interest, such as depleted uranium (DU), to the Environmental Protection Agency (EPA) Remedial Project Managers (RPM), On-Scene Coordinators (OSC), contractors, and other site cleanup managers involved with the remediation of sites contaminated with radioactive material.

This Technical Brief is intended to help the user understand the characteristics, behavior in the environment, and potential human health risks of DU as a contaminant in soils and groundwater. The document also identifies available monitoring and measurement tools and various treatment technologies for remediation of sites contaminated with DU. Supplementary discussions and additional information are provided in the appendices.

This Technical Brief specifically addresses DU in an environmental contamination setting and specifically does not consider airborne DU micro-particulates of the type associated with DU munitions. Further, it considers only contamination scenarios in the United States, though it has used international scientific data, where appropriate, for its technical basis. In these environmental contamination settings, the major risk from DU is toxicological rather than radiological, and chemical toxicity is the major driver for site cleanup.

Further, since most available literature concerning chemical properties of uranium focus on natural uranium, this document will make frequent reference to these studies in full knowledge that the chemical properties addressed for natural uranium are identical to those of DU. Addenda will be issued periodically to update the original Technical Brief, whenever deemed necessary.

2. INTRODUCTION

Depleted uranium (DU) is a byroduct of the process used to enrich natural uranium for use in nuclear reactors and in nuclear weapons. Natural uranium is composed of three isotopes; ^{234}U, ^{235}U, and ^{238}U (see Table 1) [1]. The enrichment process concentrates both the ^{235}U and the ^{234}U isotopes in the product material, resulting in a waste product or byproduct *depleted* in both ^{235}U and ^{234}U. The resultant DU retains a smaller percentage of ^{235}U and ^{234}U, and a slightly greater percentage of ^{238}U (99.8% by mass instead of 99.3%). Because of the shorter half-life of ^{234}U and ^{235}U compared to ^{238}U, the radioactivity associated with DU is approximately 40% less than that of natural uranium.

Table 1: Typical Isotopic Abundances in Natural and Depleted Uranium

Isotope	Abundance (by weight)	
	Natural Uranium	Depleted Uranium
^{234}U	0.0058%	0.001%
^{235}U	0.72%	0.2%
^{238}U	99.28%	99.8%

In the United States, DU is available mainly from the U.S. Department of Energy (DOE) and other government sources. DU occurs in a number of different compounds with different characteristics, which may have a significant impact on the management and disposition of this material.

Because DU metal is 1.7 times more dense than lead, it is valuable for industrial uses. It has been used for civil and military purposes for many years. Detailed information on uranium, its chemical forms, manufacturing/enrichment processes, and uses of DU are further discussed in Appendix 1.

2.1 Characteristics of Uranium and Depleted Uranium

Uranium is a naturally occurring radioactive metal in all rocks and soils in low concentrations (1 to several hundred picocuries per gram (pCi/g)). All three isotopes are radioactive and produce decay products upon radioactive disintegration. After purification (processing) of uranium, the decay products of all of the uranium isotopes will begin to accumulate very slowly, and traces of these decay products can be detected.

Other trace isotopes that have been observed in depleted uranium, and are likely of anthropogenic origin, include plutonium-238 (^{238}Pu), plutonium-239 (^{239}Pu), plutonium-240 (^{240}Pu), americium-241 (^{241}Am), neptunium-237 (^{237}Np) and technetium-99 (^{99}Tc).

Table 2: Radiological Properties of Uranium Isotopes

Isotope	Half-life (years)
^{234}U	2.455×10^{5}
^{235}U	7.038×10^{8}
^{238}U	4.468×10^{9}

Table 2 above lists the half-life of each isotope. Approximately 48.9% of the radioactivity of natural uranium is associated with ^{234}U, 2.2% is associated with ^{235}U, and 48.9% is associated with ^{238}U. All three isotopes behave the same chemically but have different radiological properties. As may be calculated from the tables, the radioactivity of natural uranium is approximately 0.70 μCi/g, whereas the radioactivity of DU is approximately 0.40 μCi/g.

The weight percentages in Table 1 and radioactivity percentages given previously are different because each isotope has a different physical half-life - the shorter half-life makes ^{234}U the most radioactive and the longer half-life makes ^{238}U the least radioactive. Each isotope decays by emitting an alpha particle.

For natural uranium present in soils and rocks, the activities of ^{234}U and ^{238}U are identical; they are said to be in secular equilibrium. In natural waters, however, the ^{234}U can appear to be slightly more soluble and the radioactivity ratio of ^{234}U to ^{238}U varies from 1:1 to more than 20:1. This is believed to be due to the fact that as ^{238}U decays to ^{234}U, it passes through thorium-234 (^{234}Th) (*first decay product*) and then protoactinium-234 (^{234}Pa) (*second decay product*) which are slightly more soluble than the uranium isotopes. The ^{234}U thus appears to move while the ^{238}U remains sparingly soluble. When converting from activity to mass or vice versa, knowledge of the concentration of each the three uranium isotopes is required.

2.2 Health Concerns

A common misconception is that radiation is the primary hazard DU poses to human health. This is not the case under most exposure scenarios. Though irradiation from DU can occur, chemical toxicity is usually the major hazard from soluble forms of uranium, while the radiological hazard dominates inhalation of sparingly soluble forms. Since all forms of uranium possess the same inherent chemical properties, they also display the same behaviors of chemical toxicity, and if internalized, will all lead to adverse health effects similar to those of other heavy metals such as lead and cadmium. The Agency for Toxic Substances and Diseases Registry (ATSDR) Toxicological Profile on uranium [1] summarizes the existing animal and human data on the toxicology of natural uranium.

Natural and depleted uranium differ only in their relative concentrations of uranium isotopes. Depleted uranium is roughly 60% as radioactive as natural uranium because the more radioactive isotopes have been removed. All three naturally occurring uranium isotopes emit alpha particles as their primary radiation. Because alpha particles cannot penetrate the skin, uranium is usually considered an internal radiological hazard rather than an external radiation hazard. Awareness should be maintained regarding the external hazard since DU can contain trace amounts of ^{236}U and other substances (such as plutonium, americium, and technetium); however, the risk posed by these trace contaminants is usually regarded as insignificant.

2.2.1 Exposure Pathways

Uranium occurs widely in the environment, and as a consequence small amounts of natural uranium in air, water, and soil are ingested and inhaled every day. This normal intake results in a natural level of uranium in the body of approximately 90 μg [1]. Excess loading occurs through three exposure pathways – inhalation, ingestion, and dermal contact – though the latter (dermal) is usually considered to be an insignificant exposure scenario.

Inhalation is the most likely route of intake of DU. In the case of sites contaminated with DU, this may occur through resuspension in the atmosphere through wind or dust disturbances due to site operations. Accidental inhalation may also occur as a consequence of fire in a DU storage facility, an aircraft crash, manufacture of armor-piercing weapons, or the decontamination of contaminated objects. [34]

Ingestion can occur in a large section of a community or population if drinking water or food supplies become contaminated with DU. In addition, ingestion of soil by children is considered a potentially significant pathway [34].

Dermal contact is considered a relatively unimportant type of exposure since little of the DU will pass across the skin into the blood. However, DU could enter systemic circulation through open wounds or from embedded fragments of DU [34].

2.2.2 Chemical Risk

When incorporated into the body, the highest concentrations of uranium occur in the kidneys, the most sensitive organ, as well as liver tissue and skeletal structure. The amount of DU subsequently absorbed into the blood and deposited in the kidneys or other organs is dependent upon several factors (e.g., exposure pathway, particle size, solubility) [1]. DU particles and oxides retained in the body have different solubilities. The three uranium oxides of primary concern (UO_2, UO_3, and U_3O_8) are relatively insoluble [35]. Insoluble and sparingly soluble uranium compounds are believed to have little potential to cause renal toxicity but could cause pulmonary toxicity through inhalation exposure [1].

The ingestion exposure pathway currently has a number of established risk levels and standards for chemical toxicity. ATSDR has a "minimal risk" level for intermediate-duration ingestion set at an oral uptake of 2 µg of uranium per kg of body weight per day, though the World Health Organization (WHO) has established a tolerable daily intake (TDI) for uranium of 0.6 µg/kg body weight per day. WHO has a provisional guideline for drinking water quality of 15 µg/L - a value considered to be protective for sub-clinical renal effects reported in epidemiological studies. EPA's Rule on Radionuclides in Drinking Water sets a maximum contaminant level for naturally occurring uranium at 30 µg/L, and its preliminary remediation goal (PRG) for Superfund is 2.22 µg/L for ^{238}U in tap water. The Nuclear Regulatory Commission's occupational annual limit on intake (ALI) for oral ingestion is 14.8 mg.

2.2.3 Radiological Risk

The general population is exposed to uranium primarily through food and water with an average annual intake from all dietary sources being about 350 pCi [31]. On average, approximately 90 µg (micrograms) of uranium exists in the human body from natural intake of water, food, and air. About 66% is found in the skeleton, 16% in the liver, 8% in the kidneys, and 10% in other tissues [32]. In the United States, the typical concentration of uranium in the skeletal structure (wet weight) is about 0.2 pCi/kg [31]. The lungs, kidneys, and bone receive the highest annual doses of radiation from uranium, estimated at 1.1, 0.92, and 0.64 mrem, respectively, for U.S. residents.

As they decay, DU and its decay products emit alpha, beta, and gamma radiation that can result in external and internal exposure to those who handle or encounter DU-contaminated materials. Based on the zero-threshold linear dose response model, any absorbed dose of uranium is assumed to result in an increased risk of cancer. Since uranium tends to concentrate in specific locations in the body, the risk of cancer of the bone, liver, and blood (such as leukemia) may be increased.

Inhaled DU particles that reside in the lungs for long periods of time may damage lung cells and increase the possibility of lung cancer after many years. DU is considered primarily an internal hazard, although there is some external radiation hazard associated with DU since its progeny emit gamma rays.

The amount of uranium in the air is usually very small and effectively insignificant for remedial operations. People who live near federal government facilities that produced or tested nuclear weapons in the past, or facilities that mine or process uranium ore or enrich uranium for reactor fuel, may have increased exposure to uranium. For example, data from the United States and Canada have shown elevated uranium levels in and around milling and processing facilities, and estimated airborne releases of uranium at one DOE facility amounted to 310,000 kg between 1951 and 1988, which produced an estimated offsite inventory of 2,130-6,140 kg of excess uranium in the top 5 cm of soil in the vicinity of the facility [34].

3. URANIUM IN THE ENVIRONMENT

Due to its natural abundance, uranium can be found anywhere in water, in food, and air. Because DU and naturally occurring uranium are chemically the same, knowledge about transformation, transport, fate and effect on natural uranium in the environment is applicable to the study of DU.

3.1 Occurrence

As an environmental contaminant, DU most frequently occurs as the metal, and as a number of solid oxides, which may include those arising from oxidation of the metal, those from hydrolysis of uranium hexafluoride accidentally released to the environment, and those from neutralization of acidic industrial wastes that contain dissolved DU. It can also occur as soluble aqueous species (primarily the uranyl ion) or as a number of insoluble and sparingly soluble species, including mineral forms that have arisen as a result of uranium's complex environmental chemistry.

3.2 Geochemistry

Oxidation-reduction processes play a major role in the occurrence and behavior of uranium in the aqueous environment. The dominant uranium valence states that are stable in the geologic environment are the uranous (U^{4+}), and uranyl (U^{6+}, UO_2^{2+} ion) states; the former is much less soluble [2] while the latter can form many complexes and is regarded as a dominant feature of uranium chemistry. For the metal, the oxidation rate is likely to be controlled by variables such as temperature, metal size and shape, presence or absence of coatings, soil matrix, and presence of water and other contaminants.

3.3 Mobility

Uranium transport generally occurs in oxidizing surface water and groundwater as the uranyl ion, UO_2^{2+}, or as uranyl fluoride or carbonate complexes. UO_2^{2+} and uranyl fluoride complexes dominate in acidic oxidizing acidic waters, whereas the carbonate complexes dominate in near-neutral and alkaline oxidizing waters, respectively. In contrast, the uranous ion, U^{4+}, is essentially insoluble. An important point in considering uranium migration in soils is that when UO_2^{2+} is reduced to U^{4+} by humus, peat, or other organic matter or anaerobic conditions, it is essentially immobilized. It should also be noted that phosphates and sulfides usually precipitate uranium and hence stop migration, a behavior that can be exploited in remedial operations.

Hydroxyl, silicate, organic, and sulfate complexes might also be important, sulfate especially in mining and milling operations that use sulfuric acid as a leaching agent. Maximum sorption of uranyl ions on natural materials (e.g., organic matter; iron, manganese and titanium oxyhydroxides, zeolites, and clays) occurs at a pH of 5.0-8.5. The sorption of uranyl ions by such natural media appears to be reversible. For uranium to be “fixed” and therefore accumulate, it requires reduction to U^{4+} by the substrate or by a mobile phase, such as hydrogen sulfide (H_2S).

3.4 Enhanced Mobility

A further complication in predicting the mobility of DU is the existence of facilitated transport. Facilitated transport is the accelerated movement of contaminants in an aqueous system at a rate greater than would be predicted by either the simple solubility of the contaminant, the formal flow-rate of the aqueous phase, or by the interaction of a contaminant with the solid phases present. Facilitated transport is usually attributed to the contaminant being bound to particles such as colloids, or having enhanced solubility due to the presence of complexants, ligands, and/ or chelators. While the aqueous phase in general may be able to explore a very tortuous path through the geologic media when contaminant attached to a particle that is too large to travel through the smaller pathways, it is effectively restricted to wider cracks and crevices, thus giving it an enhanced mobility. Colloids are typically tiny (spanning the size range from large molecules to small biological entities such as bacteria) particles of mineral and/or organic matter that can remain suspended in the aqueous phase without settling. They may be hydrolysis products of uranium, organic chelates (natural and anthropogenic ligands), or mineral/oxide/humic colloids.

4. FATE AND TRANSPORT OF DEPLETED URANIUM

Environmental contamination by DU can occur in soil, water, biota, and as airborne particles. Although the radiological properties of uranium isotopes differ considerably, their chemical behavior is essentially identical. Hence, knowledge about the transformation, transport, fate, and effect of natural uranium in the environment is applicable to DU.

Under some conditions, such as the reducing conditions characteristic of swamps and wetlands, the stable chemical form of uranium is the +4 state in which it will not readily dissolve in water, and will thus become relatively immobile. Under oxidizing conditions, such as on the surface of the ground or in shallow water, DU oxidizes to a state in which it can dissolve and become mobile in water. Metallic forms will oxidize faster as small particles than as large pieces [37].

Aside from pH, a number of other parameters affect uranium fate and transport. Other parameters that influence movement are the presence (or absence) of organic comounds, redox status, ligand concentrations (i.e., carbonate, fluoride, sulfate, phosphate, and dissolved carbon), aluminum- and iron-oxide mineral concentrations, and uranium concentrations.

Given the long half-life of uranium (see Table 2), decay is not particularly relevant to uranium fate and transport in the environment. The following sections discuss DU fate/transport by medium.

4.1 Fate in Soil

Upon weathering, non-oxidized small particles may be adsorbed to clay minerals and humus. The surfaces of remaining DU fragments in soil exposed to the atmosphere will slowly oxidize to uranium oxides.
Uranium can exist in the +3, +4, +5, and +6 oxidation states. The +4 and +6 states are the most common in the environment. These oxides are only sparingly soluble, but will gradually form hydrated uranium oxides in moist conditions. The hydrated uranium oxides will then slowly dissolve and be transported into the surrounding soil, pore water, and eventually groundwater, although adsorption of uranium to organic compounds in the soil may inhibit the rate of migration. It should be noted that the +6 form (uranyl ion) can be adsorbed on clays and organic compounds and later be “eluted” or displaced by other cations. However, many organic materials reduce the uranyl ions to the +4 forms which are not likely to be eluted, though they might be subsequently reoxidized and made soluble.)

In the case of metallic particles, the oxidation rate depends on fragment size, pH, humidity, soil moisture content, soil chemistry, soil oxygen content, and the presence of other metals in the soil. The system’s pH and dissolved carbonate concentrations are the two most important factors influencing the adsorption behavior of U^{6+} in soil [38].

Iron and manganese oxides, smectite clays, and naturally occurring organic matter can act as somewhat irreversible sinks for uranium present in soils. As a result, sorption onto iron and manganese oxides can be an effective extraction process, although the presence of dissolved carbonate can inhibit this process. Uranium transfer between these bound phases and the dissolved phase is subject to very slow reaction rates [38].

Aqueous pH influences the sorption of U^{6+} to solids. The poorer-adsorbing uranium species are most likely to exist at pH values between 6.5 and 10. Additionally, lowering the pH reduces the number of available exchange sites on variably charged surfaces, such as iron oxides and natural organic matter.

Microbial activity might speed up the corrosion of metallic DU, but it should be noted that the titanium present in DU of military origin (typically 3.5 %) would tend to counteract and slow down the process [39]. On the other hand, in soil with high concentrations of organic materials, naturally occurring soil bacteria can reduce soluble U^{6+} to sparingly soluble U^{4+}, thereby limiting uranium mobility as well. Oxygen content, presence of water, size of the metal particles, presence of protective coatings, and the salinity of the water present all impact the rate of microbial action. Although it is known that organic matter is a sink for uranium in soils and sediments, the actual mechanism of the process is still unclear [38].

4.2 Fate in Water

U^{4+} solid phases have relatively low solubilities, so the total concentration of U^{4+} in water is usually low (3-30 m g/L) [38]. In general, aqueous U^{4+} forms precipitates that are sparingly soluble, adsorbs strongly to mineral surfaces, and partitions into organic matter. All of these properties lead to its reduced mobility in water.

Under reducing conditions, U^{4+} is the dominant oxidation state in aqueous solutions. Reducing conditions are found in deep aquifers, marsh areas, and engineered barriers. U^{4+} is not strongly complexed by common inorganic ligands and is present predominantly as the $U(OH)_4$ ion under pH conditions typical of most natural waters. U^{4+} precipitates to form relatively insoluble solids, such as uraninite (UO_2) and coffinite ($USiO_4$) [40].

As previously mentioned, the U^{6+} ions can be removed from solution by sorption on iron hydroxides and organic soil matter. Sorbed uranyl ions can be reduced to U^{4+} by reductants such as hydrogen sulfide (H_2S), methane (CH_4), or ferrous iron (Fe^{2+}). If uranyl ions are sorbed by organic matter, the organic matter may reduce the uranyl ions [40]. Uranyl ions may also be removed from solution by precipitation as U^{6+} solid phases such as schoepite (∃-$UO_3 \cdot 2H_2O$), which is relatively soluble, or by precipitation of the less soluble phases carnotite ($K_2(UO_2)_2(VO_4)_2$) or tyuyamunite ($Ca(UO_2)_2(VO_4)_2$) [40].

Uranyl ions form strong complexes with carbonate ion in solution. These carbonate complexes increase the solubility of uranium solids, facilitate U^{4+} oxidation, and increase uranium mobility by limiting uranium sorption in oxidized waters [40]. Fluoride, phosphate, and sulfate ligands can also significantly complex uranyl ions [40].

At low ionic strengths with low concentrations of U^{6+}, the concentration of dissolved U^{6+} is mostly controlled by cation exchange and adsorption processes. As the ionic strength of a solution increases, other cations (e. g., Ca^{2+}, Mg^{2+}, K^{+}) displace any uranyl ions on soil exchange sites and force them back into solution.

4.3 Fate in Air

Atmospheric releases of DU are almost exclusively in particulate form, as the vapor and gas forms of DU are not commonly encountered. The high density of DU in most particulate forms limits the air transport of DU to relatively small particles. Air releases of DU can occur via emission from stacks, re-suspension from soil, or through emissions of fugitive dust from piles or industrial process areas containing DU.

Source estimates for stack releases are generally derived from stack monitors. The revised wind erosion equation [41] may be used to estimate releases via suspension from soil. Sources of fugitive dust releases to air are often estimated using the EPA AP-42 guidance [42]. Air transport of long-term (∃one year) releases of DU in the form of aerosols or other respirable particle sizes is typically analyzed using codes based on the Gaussian plume model. These models estimate air concentrations as a function of direction and distance from the source, and also will usually provide estimates of ground concentrations resulting from deposition of the airborne DU. It is reported that most of the DU dust will be deposited within a distance of 100 meters from the source [43].

Following airborne transport, the migration of DU will ultimately become subject to water, soil, and biological transport mechanisms. In general, DU deposited by airborne transport will be present on or near the soil surface and shows minimal uptake by plant roots. DU is not effectively transported through the food chain, as low-level organisms tend to excrete the soluble uranium species quickly.

4.4 Fate in Biota

Some plant material, such as lichens, can serve as an indicator of airborne DU contamination. Lichens consist of fungi and algae living together symbiotically, in a mutually beneficial way. As lichen morphology does not vary with the seasons, their accumulation of pollutants can occur throughout the year, and they usually live for very long periods.

Some lichens growing on the surface of another plant have a high capacity to accumulate uranium. Because they lack roots, lichens do not have access to soil nutrient pools and accumulate substances mainly via trapping atmospheric particulates. Uranium is accumulated in lichen thallus under moist and dry conditions from airborne particles and dust. Even tiny fragments of lichens may contain concentrations that are readily detectable [43].

4.5 Partition Coefficients

Partition coefficient (K_d) is a parameter used when estimating the migration potential of contaminants present in aqueous solutions in contact with surface, subsurface, and suspended solids. K_d is defined as the ratio of the contaminant concentration associated with the solid to the contaminant concentration in the surrounding aqueous solution when the system is at equilibrium. Generic or default partition coefficient values found in literature can result in significant errors when used to predict the absolute impacts of contaminant migration or site-specific remediation options. Partition coefficient values measured at site-specific conditions are essential for site-specific calculations [44].

With respect to uranium movement in the environment, however, the EPA guidance on K_d suggests that the best way to model the concentration of precipitated uranium is through the solubility constants of the different uranium compounds iovolved, rather than through K_d [44].

As with other uranium properties, uranium K_d values are strongly influenced by pH because of the pH-dependent surface charge properties of soil minerals and the complex aqueous speciation behavior of dissolved U^{6+}. In general, at pH less than 3, the adsorption of uranium by soils and single-mineral phases in carbonate-containing aqueous solutions is low, reaching a maximum in adsorption between pH 5-8, then decreasing at pH values greater than 8 [44]. Table 3 provides minimum and maximum K_d values for uranium as a function of pH and shows the wide variation that occurs in K_d.

4.6 Fate and Transport Modeling

Obviously, the best method for determining the concentration of a contaminant at a location in a contaminated site is by direct, site specific measurement using the appropriate analytical method and protocol. The contaminant concentration is then usually used to determine K_d for further modeling purposes. The use, advantages, and limitations of the K_d approach have been well discussed in the literature [43], and we recommend that whenever possible K_d should be measured. It is important to note that soil scientists and geochemists knowledgeable of sorption processes in natural environmennts have long known that generic or default partition coefficient values found in the literature can result in significant errors when used to predict the absolute impacts of contaminant migration or site-remediation options. Accordingly, one of the major recommendations is that for site-specific calculations, partition coefficient values measured at site-specific conditions are absolutely essential [43]. However, due to the complexities of both geological media and chemical behavior within this media, the necessary measurements of contaminant concentration may not be possible. For example, at a given point in a geological matrix, a contaminant will be partitioned between the groundwater and the host geological matrix, and a "true" measurement at that point requires removal of a sample containing both the solid and aqueous phase; this may not always be easy to achieve. If such problems are the case, or if the contaminant has not yet reached exposure points, environmental fate and transport models must be used to predict contaminant concentrations.

Table 3: K_d Values for Uranium as a Function of pH

pH	K_d (mL/g) Minimum	Maximum
3	<1	32
4	0.4	5,000
5	25	160,000
6	100	1,000,000
7	63	630,000
8	0.4	250,000
9	<1	7,900
10	<1	5

Source: [44 - Table 5.15]. (See also reference 43, Table 5.18 and pages 5.79 – 5.81)

While many fate and ransport models are available for various media, this type of modeling is an area of active research with much debate on the problems associated with existing models and little consensus on how chemical reactions and reaction parameters should be determined for field applications. The Federal Interagency Steering Committee on Multimedia Environmental Models (ISCMEM) exists to coordinate efforts among agencies that actively use or support the development of coupled hydrologic and geochemical models to simulate the transport of chemical contaminants in the subsurface environment.

Fate and transport modeling is of great importance in radiation risk assessments and conceptual site models required for remediation, and considerable importance is attached to the availability of expertise in their use.

5. SITE SCREENING FOR DEPLETED URANIUM CONTAMINATION

EPA has published several guidance documents on the approach for remediation of sites contaminated with hazardous materials, including radionuclides. Because of the complexity and comprehensiveness of the subject matter, the reader is advised to consult the relevant details in the following documents/websites:

1. "Distribution of OSWER Radionuclide Preliminary Remediation Goals (PRGs) for Superfund Electronic Calculator", February 7, 2002. http://epa.gov/superfund/resources/radiation/pdf/rad.pdf

2. Soil Screening Guidance, User's Guide, 2nd Edition 9355.4-23, 1996. This Guide [3] provides a methodology to calculate risk-based, site-specific soil screening levels (SSL).

3. Soil Screening Guidance for Radionuclides: Technical Background Document, EPA/540-R-95/128, 1996 [4], and Soil Screening Guidance for Radionuclides: User's Guide, EPA/540-R-00-007, 2000 [5].

4. EPA website, http://www.epa.gov/radiation/radionuclides/uranium.html

5. Inventory of Radiological Methodologies for Sites Contaminated with Radioactive Materials, EPA/402-R-06-007, 2006 (See Table 10, page 42, for analytical methodologies applicable to each radionuclide, and Section 3.2.1 for discussion of water sample preservation and transport issues).

It should be noted that information on the chemical toxicity of uranium is available in the ATSDR Toxicological Profile for Uranium [1]. It should also be noted that since uranium, including DU, is both a chemical and radiological hazard, SSLs for DU should consider both types of hazards. SSLs for uranium should be calculated using both the Soil Screening Guidance for non-carcinogenic chemicals and the Soil Screening Guidance for Radionuclides. Since the SSL is a numerical concentration, it should be based on the most protective health quantity, whether that is kidney toxicity or radiological risk.

6. MEASUREMENT TOOLS AND MONITORING TECHNIQUES

Uranium and DU can be detected by measuring the different types of radiation (i.e., alpha, beta and/or gamma radiation) emitted. Presently, a vast choice of equipment for monitoring such radiation is available. Refer to Table 6, Appendix 2, for a description of selected specific measurement tools and monitoring techniques.

Measurements made with field equipment are typically less sensitive than laboratory measurements and may be impaired by environmental characteristics such as natural soil composition. If these field measurements are not, or are only partly, successful, field samples must be collected and analyzed in a laboratory in order to obtain a comprehensive assessment of the contamination.

EPA's Office of Radiation and Indoor Air completed a draft compendium on the Inventory of Radiological Methodologies, focusing on the radionuclides likely to be found in soil and water at contaminated sites. While it is not a complete catalog of analytical methodologies, it is intended to assist project managers to understand the concepts, requirements, practices, and limitations of laboratory analyses unique to radioactive environmental samples. Detailed guidance on recommended radioanalytical practices may be found in current editions of the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) [6] and the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) [7].

7. REMEDIATION TECHNOLOGIES

Technologies for the remediation of DU contamination may involve one or more of the following processes: excavation and earth moving, physical separation, chemical separation, in-situ stabilization, or a combination of these technologies. Remediation of surface and groundwater contaminated with DU may include conventional pump and treat methods and/or permeable reactive barriers. These technologies are described in the following subsections [8]. However, no technologies exist that are capable of significantly reducing the chemical and radiological toxicity of DU, characteristics also fundamental to natural uranium. Case studies of the remediation efforts of two sites with DU contamination, Nuclear Metals, Inc. in Concord, Massachusetts, and Maxey Flats in Hillsboro, Kentucky, are provided in Appendix 5 and 6. It should be noted that the following descriptions of remediation technologies are brief and serve only as a guide for further investigation and analysis. The evaluation and selection of a remediation technology can be a complex matter; critical issues include the physical and chemical forms of the depleted uranium contaminant, physical and chemical properties of the contaminated media, and the presence of other contaminants. The technologies below broadly cover DU contaminated sites, storage sites, sites associated with UF_6, and address DU-contaminated soil and groundwater. In such remedial situations, consideration must also be given to related media, such as dust with the potential to become airborne as a result of remediation operations. The scope resented here does not include air pollution such as particulates from munitions and projectiles, and in this regard it is worthy to note that EPA is unaware of any National Priority List sites associated with DU contamination arising from projectiles.

7.1 Soil Technologies

Several technologies have been developed for use on DU-contaminated soils [8]. Examples include:

- Excavation, followed by disposal of soils in a low-level waste repository; and

- Excavation of contaminated soil followed by treatment (i.e., physical separation and chemical extraction).

7.1.1 Physical Separation

Remediation of soils contaminated with metallic DU typically begins with physical removal of large fragments, either by hand sorting or by size classification using a screening device [8]. Excavation and physical separation with screening devices may be used as the principal means of remediation of contaminated soil if the contamination is associated with a particular soil size fraction. Physical separation of contaminated and uncontaminated soils may also be accomplished using magnetic separation technology; or gravimetric separation. Other proprietary devices include the Segmented Gate System (SGS), produced by the Eberline Instrument Corporation, which monitors radiation in soil as the soil moves along conveyor belts and then diverts the contaminated material [8] [9]. After separationof the contaminated and uncontaminated soil fractions, the uncontaminated soils are used as clean fill, and contaminated soils are treated or processed for disposal. The volume reduction of contaminated soil that requires disposal or treatment can result in significant cost savings [10].

7.1.2 Chemical Extraction

Chemical extraction methods (also referred to as soil washing or heap leaching) use water with various chemical additives to dissolve DU from contaminated soils. The chemical additives include oxidants to convert relatively insoluble U^{+4} to the more soluble U^{+4} form, complexing agents such as carbonate that increase uranium solubility, and strong acids or bases [8] [9] [10] [11]. The cleaned soil is then generally used as fill material, and leachate containing the uranium and other contaminants is often treated to remove contaminants in a concentrated form for disposal [8].

7.2 *Groundwater Technologies*

Technologies for the treatment of DU in groundwater include:

- Treatment of groundwater contamination by conventional pump and treat methods;
- Treatment of groundwater contamination by permeable reactive barriers; and
- Emerging/Pilot Studies treatments.

7.2.1 Pump and Treat

Pump and treat methods remove contaminated groundwater from the aquifer and can be used to contain and manage migration of contaminant plumes. Pump and treat methods involve pumping contaminated water from the ground, treating it, and either injecting it back into the aquifer or discharging it to a suitable surface system.

7.2.2 Permeable Reactive Barriers

Permeable reactive barriers are passive systems consisting of reactive materials placed in the subsurface. As groundwater flows through the system, the reactive materials in the permeable barrier remove and immobilize the contaminants [12] [13] [14]. Reactive materials used to remove uranium from groundwater in these systems typically include different forms of metallic (zero-valent) iron [13], but other materials (e.g., amorphous ferric oxyhydroxide) have also been used to remove uranium from groundwater (www.gjo.doe.gov). A disadvantage of using metallic iron is that the uranium is removed by a precipitation reaction and the precipitate product has a tendency to clog the barrier, thus reducing its long-term effectiveness. In contrast, the use of a material such as apatite, a calcium phosphate mineral, leads not only to the formation of sparingly soluble uranium phosphate minerals but also to adsorption of uranyl carbonate complexes on the apatite surface with little clogging.

Examples of the effective use of permeable reactive barriers to remove uranium from groundwater include installations at Fry Canyon, Utah, and Durango, Colorado (www.gjo.doe.gov). A permeable reactive barrier system has also been used to remove uranium from contaminated groundwater in an area known as the mound site plume at DOE's Rocky Flats Environmental Technology Site (RFETS) in Colorado [15]. It is important to note that the mode of action of permeable barriers leaves the contaminant in place unless the barrier is excavated (usually at great cost), so barrier longevity and long-term performance are important engineering issues.

7.2.3 Commercial Test Studies

Several research and development (emerging) processes have been tested on a pilot scale by Water Remediation Technology, LLC, (WRT) of Arvada, Colorado, using an adsorptive media Z-92^{TM}, for treatment of well waters contaminated with uranium in excess of the maximum contaminant level (MCL). WRT conducted three studies at Brazos Mutual Domestic Water in New Mexico [16]; the Mountain Water & Sanitation District in Conifer, Colorado [17]; and the Fox Run Water Company at Chesdin Manor in Dinwiddie County, Virginia [18]. In each of these studies, municipal water suppliers had wells that contained water with concentrations of uranium in excess of the MCLs. WRT provided pilot scale (approximately one gallon per minute) and larger scale (80 gallons per minute) systems using the Z-92™ media to demonstrate the effectiveness of the treatment process, establish design parameters for the full-scale systems or document the effectiveness of the WRT system, and meet regulatory compliance requirements. In each case, the pilot unit or larger scale system successfully met gross alpha and uranium compliance at all times.

7.3 *Technologies for Soil and Water*

Several technologies can be used to treat either soil or groundwater. Examples include:

- In-situ stabilization, through the use of amendments, grouting, or capping of contaminated soil; and

- Phytoremediation, in which plants are used to extract contaminants from soil or groundwater.

7.3.1 In-Situ Stabilization/Treatment

In-situ stabilization, treatment, and amendment methods are available for immobilizing uranium contamination in soils and groundwater [10]. The addition of amendments (e.g., apatite or phosphate solutions) stabilizes uranium in soils and groundwater through the formation of relatively insoluble uranium-phosphate solids [10] [19] [20]. Grouting or capping of contaminated soils and sediments may also be used to stabilize uranium contamination in place [10]. As with permeable reactive barriers, stabilization leaves the contamination in place. Precipitation of uranium to the phosphate form leaves uranium highly insoluble and essentially inert chemically. Even ingestion would not result in much uranium retention in the body. Nevertheless, most methods for screening for uranium would show that the uranium was still present, and it may be difficult to be sure that the uranium found by screening is effectively stabilized as the phosphate.)

7.3.2 Phytoremediation

Phytoremediation refers to the utilization of green plants' natural absorption of specific components of their host growing medium; it is an emerging, rather than established, technology for remediation. Uptake of uranium by plants is typically small [21] [22]. However, phytoremediation of uranium using sunflowers (genus *Helianthus)* has been demonstrated with uranium waste at Ashtabula, Ohio, and at a small pond contaminated with uranium near the Chernobyl nuclear power plant site in Pripyat, Ukraine [23]. Phytoremediation using Indian mustard (*Brassica juncea*) of DU contamination at a firing range at the Aberdeen Proving Ground in Maryland has also been demonstrated [24]. Phytoremediation of uranium is accomplished through the process of rhizofiltration in which plant roots sorb, concentrate, and precipitate metal contaminants from surface or groundwater [23]. The concentration of uranium contamination removed from the soil by the plants can reduce the volume of material that otherwise would need be removed for disposal.

A requirement of phytoremediation is that a proper disposal approach must be adopted for the contaminant-bearing plants to prevent cross media transfer of contaminants and subsequent exposure. For inorganic contaminants such as uranium, simply burning the plants will not destroy the contaminant.

7.3.3 Monitored Natural Attenuation

In addition to the remediation technologies described above, the use of monitored natural attenuation (MNA) may be applied as an optional process, which should be evaluated with other applicable remedies (including innovative technologies) for restoring contaminated groundwater, preventing migration of contaminant plumes, and protecting groundwater and other environmental resources.

MNA refers to the reliance on natural attenuation processes (including a variety of physical, chemical, or biological processes) to achieve site-specific remediation objectives within a reasonable timeframe compared to other more active methods. In order for natural attenuation to be selected as a remedy, determining the existence and demonstrating the stability and irreversibility of these mechanisms is important to show that a MNA remedy is sufficiently protective. Additionally, site-specific determinations will always have to be made to ensure that sorption capacity of the subsurface is sufficient to be fully protective of human health and the environment. [25]

8. EPA STANDARDS APPLICABLE TO DEPLETED URANIUM SITES

When contaminated sites to be released for public use are to be remediated to meet EPA's media specific risk-based standards or criteria, several potential drivers for the remediation need to be considered. Various statutes apply to different aspects of the remediation process. Table 4 lists the major statutes that apply to various media that may come into consideration during remediation. The following sections also provide further details of the drivers. It should be noted that the discussion presented here is not intended to be comprehensive, but is provided as a starting point for further investigation.

Table 4: Main Statutes Applying to Various Media in the Remediation Process.

Media	Statute
Air	CAA
Water	SDWA
Soil	CERCLA, RCRA
Waste	NRC regulations, DOE Orders

8.1 For Soil

Under CERCLA/RCRA, EPA's site cleanup standards limit a person's increased chance of developing cancer to between 1 in 10,000 and 1 in 1,000,000 from residual uranium on the ground [26]. Site-specific factors are weighed in establishing the actual clean up value.

8.2 For Air

Under the CAA, EPA established the amount of uranium in the air as the maximum dose to an individual not to exceed 10 millirems (mrem) per year [27].

8.3 For Water

Pursuant to the SDWA, EPA established an MCL of 30 micrograms per liter (:g/L) for uranium in drinking water [28].

8.4 Storage of Depleted Uranium

DU is not stored widely around the country; the majority of the inventory of DU is stored at United States Enrichment Corporation (USEC) sites or at DOE sites. DU stored by the military is only a fraction of the total. It should be noted that under the Atomic Energy Act (AEA), the storage of depleted uranium hexafluoride (DUF_6) is self-regulated by the DOE. DU is mainly stored in the form of uranium hexafluoride (UF_6), which is a colorless high molecular weight (352) solid, at ambient temperature. It is readily transformed into a gas at atmospheric pressure by raising its temperature above 56.5^{o}C, and into a liquid by increasing the pressure and temperature above 1.5 atmospheres and 64 ^{o}C. All three phases, solid, liquid and gas, coexist at 64^{o}C

A 2001 joint report by the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency and the International Atomic Energy Agency on Management of Depleted Uranium noted that DU arising from the operations of enrichment plants can be safely stored in different forms, including uranium tetrafluoride (UF_4), or uranium oxides (U_3O_8, UO_2, and UO_3) in coated steel containers in external yards, provided that contact with standing water is prevented and that containers are routinely inspected and localized defects leading to corrosion are treated. [29]

8.5 For Disposal

For purposes of disposal, DU is considered a low-level waste (LLW) and its disposal is subject to U.S. Nuclear Regulatory Commission (NRC) regulations and appropriate DOE Orders. Disposal of DU mixed waste having both a radioactive component and a RCRA hazardous waste component must be performed in compliance with NRC LLW requirements and RCRA hazardous waste requirements.

The Executive Summary of the DOE, Oak Ridge National Laboratory's *Assessment of Preferred DU Disposal Forms* published in June 2000 noted that "...the four potential forms of DU (DU metal, DUF_4, DUO_2, and DU_3O_8) in this study should be acceptable for near-surface disposal at sites such as the Nevada Test Site (NTS) and Envirocare." [30]. It further added that, "The DU products are considered to be low-level waste under both DOE orders and NRC regulations." It indicated the preference for disposal at "...the NTS because of its unique geohydrologic and institutional settings." The study also noted that, "Each DU form has a degree of uncertainty regarding DUF_4, DUO_2, and DU_3O_8 acceptability [for disposal at NTS], with the uncertainty decreasing in the following order: DU metal, DUF_4, DUO_2, and DU_3O_8. [30]

EPA has issued guidance entitled "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination" (OSWER No. 9200.4-18, August 22,1997) which provided clarification for establishing protective cleanup levels for radioactive contamination at CERCLA sites. The guidance reiterated that cleanups of radionuclides are governed by the risk range for all carcinogens established in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) when applicable or relevant and appropriate requirements (ARARs) are not available or are not sufficiently protective. Cleanup should generally achieve a level of risk within the 10^{-4} to 10^{-6} carcinogenic risk range based on the reasonable maximum exposure for an individual. In calculating cleanup levels, one should include exposures from all potential pathways, and through all media (e.g., soil, groundwater, surface water, sediment, air, structures, etc.) To assist with calculating risk, EPA has developed a Superfund radionuclide preliminary remediation goal (PRG) calculator. PRGs for the Superfund programs are risk-based concentrations, derived from standardized equations combining exposure information assumptions with EPA toxicity data. They are considered to be protective for humans, though not always applicable to a particular site and they do not address non-human health endpoints such as ecological impacts. PRGs are used for site "screening" and as initial cleanup goals if applicable. PRGs are not actually cleanup standards and should not be applied as such. Their role in site "screening" is to help identify areas, contaminants, and conditions that do not require further federal attention at a particular site. Additionally, they could be used to establish final cleanup levels for a site after a proper evaluation takes place. In the Superfund program, this evaluation is carried out as part of the nine criteria for remedy selection outlined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). Once the nine criteria analysis is completed, the PRG may be retained as is, or modified (based on site-specific information) prior to becoming established as a cleanup standard.

Acronyms

AEA	Atomic Energy Act
ALI	Annual Limits on Intake
ARAR	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Diseases Registry
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
DU	Depleted Uranium
EPA	U.S. Environmental Protection Agency
ISCMEM	Interagency Steering Committee on Multimedia Environmental Models
LLW	Low-Level Waste
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	Maximum Contaminant Level
MNA	Monitored Natural Attenuation
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
OECD	Organization for Economic Cooperation and Development
OSC	On-Scene Coordinators
OSWER	Office of Solid Waste and Emergency Response
PRG	Preliminary Remediation Goal
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RPM	Remedial Project Managers
SDWA	Safe Drinking Water Act
SGS	Segmented Gate System
SSL	Soil Screening Levels
TDI	Tolerable Daily Intake
USEC	United States Enrichment Corporation
WHO	World Health Organization
WRT	Water Remediation Technology, LLC

Glossary

Alpha particle – A positively charged particle made up of two neutrons and two protons emitted by certain radioactive nuclei. Alpha particles can be stopped by thin layers of light materials, such as a sheet of paper, and pose no direct or external radiation threat; however, they can pose a serious health threat if ingested or inhaled.

Becquerel (Bq) – The international, or SI, unit used to measure radioactivity, equal to one transformation (or disintegration) per second. Often radioactivity is expressed in larger units like: thousands (kBq), or millions (MBq) of Becquerels. One Curie (the traditional activity unit) is equal to 3.7×10^{10} (37 billion) Bq.

Beta particle – An electron or positron emitted by certain radioactive nuclei. Beta particles can be stopped by aluminum. They can pose a serious direct or external radiation threat. They also pose a serious internal radiation threat if inhaled or ingested.

Curie (Ci) – A traditional unit used to measure radioactivity. One Curie equals that quantity of radioactive material in which there are 3.7×10^{10} nuclear transformations per second. The activity of 1 gram of radium-226 is approximately 1 Ci.

Depleted uranium – Uranium containing less than 0.7% uranium-235, the amount found in natural uranium. (See also enriched uranium)

Enriched uranium – Uranium in which the proportion of the isotope uranium-235 has been increased. (See also depleted uranium.)

Gamma rays – High-energy electromagnetic radiation emitted by certain radionuclides when their nuclei transition from a higher to a lower energy state. These rays have high energy and a short wavelength. Gamma rays are very similar to X-rays.

Half-life – The time in which one-half of the atoms of a radioactive isotope disintegrate into another nuclear form. Half-lives vary from billionths of a billionth of a second to billions of years. Also called physical or radiological half-life.

Ion – An atom or molecule that has too many or too few electrons, causing it to have an electrical charge, and therefore, be chemically active.

Isotope – A nuclide of an element having the same number of protons but a different number of neutrons.

Maximum contaminant level (MCL) – The amount of a contaminant that may be present in drinking water under the Safe Drinking Water Act. MCLs are the standards that drinking water treatment systems must meet.

Microcurie (μCi) – One-millionth of a Curie. (3.7×10^4 disintegrations per second.)

Molecule – A combination of two or more atoms that are chemically bonded. A molecule is the smallest unit of a compound that can exist by itself and retain all of its chemical properties.

Monitoring – The use of sampling and detection equipment to determine the levels of radiation or other toxic materials in land, air, or water.

Millirem (mrem) – One-thousandth of a rem.

Neutron – A small particle possessing no electrical charge typically found within an atom's nucleus. A neutron has about the same mass as a proton.

Nuclide – A general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom.

Oxide – A compound formed by the reaction of oxygen with another element. For example, rust - ferrous oxide - is iron that has combined with oxygen.

Picocurie (pCi) – One one-millionth of a microcurie ($3.7x10^{-2}$ disintegrations per second).

Proton – A small particle, typically found within an atom's nucleus, that possesses a positive electrical charge. The number of protons is unique for each chemical element.

Rad – (See Radiation Absorbed Dose)

Radioactive decay – The process in which an unstable (radioactive) nucleus emits radiation and changes to a more stable nucleus. A number of different particles can be emitted by decay. The most typical are alpha, beta and gamma particles.

Radioactivity – The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays.

Radioisotope – An isotope of an element that has an unstable nucleus. Radioactive isotopes are commonly used in science, industry, and medicine. The nucleus eventually reaches a more stable number of protons and neutrons through one or more radioactive decays. Approximately 3,700 natural and artificial radioisotopes have been identified.

Radionuclide – An unstable form of a nuclide.

Rem – (See Roentgen Equivalent Man)

Roentgen Absorbed Dose (rad) – A basic unit of absorbed radiation dose. It is being replaced by the "gray," which is equivalent to 100 rad. One rad equals the dose delivered to an object by 100 ergs of energy, per gram of material.

Radiation Equivalent Man (rem) – A unit of equivalent dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose.

Specific activity – The activity of radioisotope per unit mass of a material, either (a) in which the radioisotope occurs, or (b) consisting of only that isotope.

Treatment – A 'treatment' technology means any unit operation or series of unit operations that alters the composition of a hazardous substance, pollutant, or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated material being treated. See Appendix 7 for complete definition.

Uranium – A naturally occurring radioactive element whose principal isotopes are uranium-238 and uranium-235. Natural uranium is a hard silvery-white shiny metallic ore that contains a minute amount of uranium-234.

X-rays – High-energy electromagnetic radiation emitted by atoms when electrons fall from a higher energy shell to a lower energy shell. These rays have high energy and a short wave length. X-rays are very similar to gamma rays.

Additional Sources of Information

The following reports, documents, and websites offer additional information about DU:

Argonne National Laboratory. *Depleted Uranium, Human Health Fact Sheet*. October 2001.

Argonne National Laboratory. Depleted UF6 Management Information Network. http://web.ead.anl.gov/uranium/

International Atomic Energy Agency. Depleted Uranium Fact Sheet. International Atomic Energy Agency Information Series, Division of Public Information, 01-01198 / FS Series 3/02/E.

North Atlantic Treaty Organization. NATO Information: Depleted Uranium. http://www.nato.int/du/home.htm

The Royal Society. The Health Hazards of Depleted Uranium in Munitions. Policy Document 7/01. May 2001. Available at http://www.royalsoc.ac.uk/

U.S. Department of Defense. Deployment Health Support. http://www.deploymentlink.osd.mil/

U.S. Department of Energy, Office of Environmental Management, Depleted Uranium Hexafluoride Management Program. *Depleted Uranium Hexafluoride Fact Sheet*. Washington, DC. Fall 2001.

U.S. Department of Energy, Office of Environmental Management and Office of Technology Development. *Depleted Uranium: A DOE Management Challenge*. Washington, DC. October 1995.

U.S. Department of Energy, Office of Nuclear Energy, Science, and Technology. Final Programmatic Environmental Impact Statement for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride. April 1999. http://web.ead.anl.gov/uranium/documents/nepacomp/peis/index.cfm

U.S. Environmental Protection Agency. *EPA Facts About Uranium*. July 2002. http://www.epa.gov/superfund/resources/radiation/pdf/uranium.pdf

U.S. Environmental Protection Agency. Soil Screening Guidance for Radionuclides: Technical Background Document. Office of Radiation and Indoor Air, EPA/540-R-00-006. OSWER Directive 9355.4-16. October 2000. http://www.epa.gov/superfund/resources/radiation/radssg.htm

U.S. Environmental Protection Agency. Soil Screening Guidance: A User's Guide. OSWER 9355.4-16A. October 2000.

U.S. Environmental Protection Agency. Common Radionuclides Found at Superfund Sites. OSWER 9200.1-34. July 2000. http://www.epa.gov/superfund/resources/radiation/pdf/nuclides.pdf

U.S. Environmental Protection Agency. Field Demonstration of Permeable Reactive Barriers to Remove Dissolved Uranium from Groundwater: Fry Canyon, Utah, September 1997 through September 1998 Interim Report. Air and Radiation Emergency Response. EPA 402-C-00-001. November 2001

World Health Organization, Department of Protection of the Human Environment. *Depleted Uranium: Source, Exposure, and Health Effects*. Geneva, April 2001.

Nuclear Energy Agency, Organization for Economic Cooperation and Development; Environmental Remediation of Uranium Production Facilities, A joint report by the OECD-NEA and the International Atomic Energy Agency (IAEA).

National Research Council. Evaluation of Guidelines for Exposure to TENORM. 1999. Pgs. 33, 34, & 76.

Appendix 1: Technical Background on Uranium and Depleted Uranium

Origin and History

After the discovery of fission, it was realized that to produce a practical military weapon, the much rarer isotope of ^{235}U would have to be separated from the much more common ^{238}U isotope. In the United States, massive efforts were undertaken, as part of the Manhattan Project, to produce uranium enriched in ^{235}U.

Enrichment is a process that increases the amount of one isotope relative to another. Regardless of the enrichment method utilized for uranium, large quantities of uranium depleted in ^{235}U, are generated as a waste product. This waste became known as depleted uranium, or DU.

Production of highly enriched uranium (HEU) ended in 1992 due to the decreased needs of U.S. defense programs. In 1993, the United States Enrichment Corporation assumed responsibility for the production of low-enriched uranium (LEU) for commercial nuclear reactor fuel. As a result of past enrichment activities, DOE currently maintains a large inventory of DU, most of it stored in the form of uranium hexafluoride. Smaller quantities of DU are stored in the form of uranium metal, uranium metal alloys, and uranium oxides.

Uses of Depleted Uranium

The most well known use vfor DU is in the manufacture of armor-piercing projectiles due to its high density and pyrophoric properties. It is also used for other military purposes to reduce the effect of other conventional munitions. Civil applications are also prevalent, including use in counterweights in aircraft, missiles, racing sailboat keels, and as a material used in hospitals for shielding X-rays or gamma radiation from equipment used for radiation therapy. Below are further discussions of some of these applications.

Further Enrichment

DU was once proposed as a feedstock for further uranium enrichment. This application has been postponed indefinitely because of the present low cost of uranium ore. It should be noted that, like the initial enrichment process, any further enrichment of DU would result in small quantities of "enriched" uranium and about the same amount of DU. The DU would contain an even smaller proportion of ^{235}U than the original DU.

Nuclear Reactor Fuel

While DU cannot be used directly in nuclear reactor fuel, it can be used as a fertile material in a breeder reactor to produce plutonium-239 (^{239}Pu). The plutonium, once extracted, can be blended with DU to make mixed oxide (MOX) reactor fuel (typically 6% Pu and 94% DU).

Down-blending Highly Enriched Uranium

DU could be blended with weapons grade highly enriched uranium (HEU) to make commercial reactor fuel. This option is one method to reduce the quantity of HEU, as part of a reduction in the nuclear weapons stockpile.

Munitions

DU metal has been used in conventional military applications, most notably in tank armor and armor-piercing projectiles. Conventional weapons using DU were used in the 1991 and 2003 Gulf Wars and in NATO operations in Kosovo and Bosnia.

Shielding

The high atomic number (Z=92) and high density (19.5 g/cm^3) make DU an excellent potential material for shielding persons or equipment from X-rays and gamma rays.

Counterweights

The high density that, in part, makes uranium such an attractive shielding material also makes it suitable as a small but heavy counterweight in aircraft and other similar applications.

It should be noted that Military Specification MIL-U-70457 stipulates that DU used by the U.S. Department of Defense (DoD) must have a ^{235}U concentration of less than 0.3% by weight. Most DU has a ^{235}U concentration of approximately 0.2% by weight. In addition to ^{234}U, ^{235}U, and ^{238}U, DU may contain trace amounts of ^{236}U. The detection of ^{236}U indicates that part of the depleted uranium originated from reprocessed uranium.

To date, the above uses of DU have consumed only a small portion of the DU in storage. A number of other uses for DU have been proposed, some of which might result in the consumption of a significant amount of the stored DU. Additional proposed uses include the following.

High-Density DU Shielding

DU metal has been used in some shielding applications, but the high cost of converting UF_6 to metal has prevented more widespread use. One proposal being considered is to incorporate DU into concrete for applications in self-shielded storage boxes for radioactive waste and dry spent fuel storage shields for onsite storage of civilian reactor fuel.

Cask Fill Material, Repository Inert Material, or Back Fill Material

Depleted UO_2 has been proposed for use as a fill material in spent fuel nuclear waste containers. The concept is intended to provide additional shielding, reduce the likelihood of criticality accidents, and reduce the long-term release of radionuclides. For similar reasons, DU has also been proposed as a repository inert or backfill material.

Counterweights for Forklift Trucks

Use of DU metal, clad in protective steel shielding, in fork lifts as counterweights would result in the design of forklifts that could lift heavier loads, while at the same time reduce the turning radius of the forklift. This would allow the forklift to work in narrower aisles, increasing the usable warehouse floor space.

Depleted Uranium and its Chemical Forms

DU can exist in any chemical form in which uranium occurs. Since all isotopes of an element undergo the same reactions in nature and have almost identical physical characteristics, natural, enriched and depleted uranium are essentially chemically identical. Each isotope has the same chemical reactions in the environment, and the same biochemical and biological effects on the human body. Any differences exist because of small mass differences between various isotopes.

Chemically, DU is identical to "normal" uranium. Uranium is the heaviest existing natural element and can react with most elements except rare gases. In the air, it forms oxides such as uranium oxide (UO_2) and triuranium octaoxide (U_3O_8). At room temperature, humidity can promote the oxidation of uranium. When uranium is fragmented in chips, powder, and turnings, the metal becomes pyrophoric, spontaneously ignites in air. Uranium is produced in a number of chemical forms, including uranium oxides, uranium hexafluoride, uranium tetrafluoride, and uranium metal. These forms are explained below in greater detail. The physical properties of some of the most important uranium compounds are given in Table 5.

Uranium Oxides

Uranium oxides include U_3O_8, UO_2, and uranium trioxide (UO_3). Both U_3O_8 and UO_2 are solids that are relatively stable over a wide range of environmental conditions, with a low solubility in water. In these forms, the DU is chemically more stable and suitable for long-term storage or disposal. U_3O_8 is the most stable form of uranium and is the form most commonly found in nature. The most common form of U_3O_8 is "yellow cake," a solid produced during mining and milling operations, and named for its characteristic yellow color. UO_2 is a solid ceramic material, and the form of uranium most commonly used in nuclear reactor fuel. At ambient temperatures, UO_2 gradually converts to U_3O_8.

Uranium Hexafluoride

Uranium hexafluoride is the chemical form of uranium used during enrichment. UF_6 can be a solid, liquid, or gas within a reasonable range of temperatures and pressures. Solid UF_6 is a white, dense, crystalline material, resembling rock salt. While UF_6 does not react with oxygen, nitrogen, carbon dioxide, or dry air, it does react with water or water vapor to form corrosive hydrogen fluoride (HF) and uranyl fluoride (UO_2F_2). Because UF_6 reacts with water, including humidity in the air, it is always handled in leak-tight containers or processing units. Although very convenient for processing, UF_6 is not favored as a chemical form for long-term storage or disposal because of its relative instability.

In uranium conversion and enrichment processes, a major hazard is the handling of uranium hexafluoride (UF_6), which is chemically toxic. Uranium in these situations can also react with moisture to release highly toxic hydrofluoric acid.

Uranium Tetrafluoride

Uranium tetrafluoride (UF_4), sometimes called green salt because of its characteristic green color, is a solid composed of agglomerating particles with a texture similar to baking soda. It is nonvolatile, nonhydroscopic, and slightly soluble in water. When exposed to water, UF_4 slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). UF_4 is generally an intermediate in the conversion of UF_6 to uranium oxide (UO_2 or U_3O_8) or uranium metal.

Uranium Metal

Uranium metal is among the densest materials known, with a density of 19 grams per cubic centimeter (g/cm^3). The silvery white, malleable, and ductile metal is not as stable as uranium oxide and will undergo surface oxidation. It tarnishes in air, with the oxide film preventing oxidation of the bulk material at room temperature. Uranium metal powder or chips will ignite spontaneously in air at ambient temperature.

Manufacturing/Enrichment Processes

To produce uranium for commercial reactor fuel or military applications, the uranium must first be mined, milled, enriched, and converted to a usable form. Uranium ore contains about 0.1% uranium by weight. This ore is processed at mills using mechanical and chemical measures to separate the uranium from the remainder of the ore. The uranium mills produce "yellow cake," a powder containing mostly U_3O_8.

Since isotopes of the same element have the same chemical properties, enrichment must be accomplished by using processes that are based on the physical differences between isotopes, such as mass. A number of methods have been developed to enrich uranium, including gaseous diffusion, gas centrifuge, and electromagnetic separation. In gaseous diffusion, enrichment is accomplished by first converting the yellow cake (U_3O_8) into uranium hexafluoride (UF_6), a highly corrosive gas. This gas is allowed to pass through a porous barrier, where the lighter ^{235}U molecules are slightly more likely to pass through the barrier than the heavier ^{238}U molecules. Because $^{235}UF_6$ and $^{238}UF_6$ molecular weights are nearly the same, the gas is only slightly enriched in a single stage. The gas is passed through many stages, until the ^{235}U fraction in the gaseous UF_6 is increased to the required enrichment. In addition to the enriched uranium produced, a large quantity of DU, containing about 0.2% ^{235}U, is also generated as a byproduct.

Some of this DU has been used to manufacture armor-piercing penetrators and armor. Army contractors manufacture penetrators from DU metal at contractor-owned, contractor-operated facilities. The U.S. Nuclear Regulatory Commission (NRC) and Agreement States license these contractors to possess and store DU and to manufacture munitions components from it. A typical license would allow a contractor to receive depleted UF_6, transport it to a manufacturing facility, convert it into UF_4 and/or metal, and sell the DU components to an authorized buyer. Most of the depleted uranium hexafluoride (DUF_6) is stored in cylinders at the gaseous diffusion plants where it was generated.

USEC was created as a government corporation to shift some of the enrichment capacity from military to civilian use. In the early 1990s, USEC was created as a government corporation that became USEC, Inc. when it was privatized in 1998. Today, USEC, Inc. is the world's leading supplier of enriched uranium fuel for commercial nuclear plants. They currently manage enrichment processes out of the Paducah, Kentucky, plant and perform research and laboratory functions out of the Portsmouth, Ohio plant.

DUF_6 can be stored in three forms –liquid, gaseous, or solid. At ambient temperatures and pressures DUF_6 is a solid; therefore, it is not easily released from the storage container. When DUF_6 mixes with the water vapor in the air and the iron of the cylinders, a plug of solid uranium and iron compounds and a small amount of HF gas is created, limiting the amount of material released from a breached cylinder.

Most of DOE's DU inventory contains between 0.1 to 0.4 weight-percent uranium-235, in the form of uranium hexafluoride (UF_6) or uranium tetra-fluoride (UF_4), well below levels necessary to create a nuclear chain reaction. A large stockpile has been contained primarily in the form of UF_6 in metal cylinders stored at DOE's enrichment facilities. DU manufacturing and testing facilities in the United States are provided in Appendix 4, while Appendix 3 contains a listing of sites on the NPL that have or may have DU contamination.

Table 5: Physical Properties of Uranium Compounds

Compound	Melting Point (°C)	Density (g/cm^3)		Solubility in Water at Ambient Temperature
		Crystal Particle	Bulk	
Uranium Hexafluoride (UF_6)	64.1	4.68	4.6	Decomposes to UO_2F_2
Uranium Tetrafluoride (UF_4)	960 ± 5	6.7	2.0-4.5	Very Slightly Soluble
Uranyl Fluoride (UO_2F_2)	Decomposes to U_3O_8 at 300	6.37	~2.6	Soluble
Triuranium Octaoxide (U_3O_8)	Decomposes to UO_2 at 1,300	8.30	1.5-4.0	Sparingly Soluble
Uranium Dioxide (UO_2)	2,878 ± 20	10.96	2.0-5.0	Sparingly Soluble
Uranium Metal (U)	1,132	19.05	19	Sparingly Soluble

Source: http://web.ead.anl.gov/uranium/guide/ucompound/propertiesu/tablephysprop.cfm

Appendix 2: Measurement Tools and Monitoring Techniques

Monitoring uranium in the environment includes both field measurements and analysis of environmental samples in the laboratory. Since there is considerable natural uranium around in all soils and the concentration of natural uranium varies greatly, analyses for uranium alone may not tell any one if DU is present, and so isotopic analyses are generally needed. This is also important since, although there is little difference between the hazard from natural uranium and that from DU, there could be serious legal issues when a site could be responsible for the DU, but not for the natural uranium. DOE has had cases where the total uranium present could have been either background or from leaks or emissions.

The following sections provide some introductory information on measurement tools and monitoring techniques used for uranium. It should also be noted that EPA has recently published an inventory of radiological methodologies for sites contaminated with radioactive materials (see reference 4 on page 9) and the interested reader is referred to this document for further information.

Field Measurements

Field measurements are typically performed using hand-held survey meters, capable of detecting alpha particles while discriminating against beta particles. These instruments typically provide an estimate of the surface contamination due to all alpha emitting radionuclides present. Alpha scintillation (ZnS) detectors have been commonly used in the past, but large-area gas-flow proportional counters have often been found to be more suitable for remediation efforts where lower detection limits are required [1].

The Measurements Applications and Development Group at Oak Ridge National Laboratory (ORNL) compared the performance of several hand-held detectors commonly used to detect DU in soil [45]. Detectors reviewed included a Field Instrument for Detection of Low Energy Radiation (FIDLER), a 1.25” x 1.5” sodium iodide (NaI) detector, and open and closed window pancake-type detectors. The open-window pancake detector showed the best detection sensitivity, although the NaI detector systems provided more consistent results.

Field measurements using survey meeters are best uited for identifying surface contamination. The detection of DU below the surface using hand-held proportional counters, ionization chambers, and GM counters is inhibited by the absorption of alpha and beta particles in the soil. Hand-held gamma ray spectrometers can detect DU below the surface, but the lack of a high-energy, high-yield gamma-ray emission by ^{238}U significantly reduces the effectiveness of this technique for field identification and survey [46].

Laboratory Analysis of Environmental Samples

A number of analytical methods have been developed to quantify uranium in environmental samples. Environmental media that have been analyzed include air filters, swipes, biota, water, and soil [1]. Analytical methods include both chemical methods that usually determine only the total quantity of uranium, and radiological methods that can determine the quantity of individual uranium isotopes. Chemical methods include kinetic phosphorescence analysis, X-ray fluorometry, and mass spectrometry. Among the most common radiological methods are alpha spectrometry, gamma ray spectrometry, delayed neutron counting, and instrumental neutron activation analysis. These methods are briefly described below.

Kinetic Phosphorescence Analysis (KPA)

KPA is a method that uses a laser to excite uranium in an aqueous solution and then measures the emission luminescence intensity over time. The intensity of the luminescence is proportional to the total quantity of uranium in the sample. The technique provides no information about the relative isotopic abundances of uranium and, therefore, cannot distinguish DU from natural uranium in the sample.

X-Ray Fluorometry (XRF)

XRF is similar to KPA, but uses X-rays to excite secondary X-ray fluorescence in the sample material. The secondary X-rays have wavelengths characteristic of the element that produced them. The X-rays are separated by wavelength by Bragg diffraction in a crystal with the appropriate lattice spacing. The measurement of the intensity of the X-rays at the characteristic wavelength provides quantitative information about trace elements in the sample material, including uranium. XRF does not provide information about the isotopic composition of the uranium in the sample.

Mass Spectrometry (MS)

MS is a technique that separates and analyzes ions based on the ratio of the mass to the charge. Unlike most chemical methods, this method provides quantitative information about both the total quantity of uranium in the sample and the isotopic composition. The two most common MS techniques for quantification of uranium in environmental samples are thermal ionization mass spectrometry (TIMS) and inductively coupled plasma-mass spectrometry (ICP-MS). Until recently, TIMS had been the preferred method for the determination of uranium isotopic ratios in environmental samples because of its superior sensitivity, accuracy, and precision, but ICP-MS has been shown to provide similar accuracy and precision, with higher sample throughput and ease of use [46].

Alpha Spectrometry

Alpha spectrometry is a method that relates the quantity of a given alpha-emitting radionuclide to the number of alpha particles detected. Since radionuclides emit alpha particles at one or more discrete energies, it is possible to relate the area of a peak in the alpha spectrum to the quantity of a radionuclide in the sample. Alpha particles continuously lose energy to the electrons in the medium they are traveling in, and will travel only a short distance before they lose all their energy. For this reason, samples should be kept thin and placed near the detector.

Gamma Spectrometry

Gamma spectrometry involves the detection of gamma rays emitted by radionuclides. Radionuclides typically emit gamma rays at one or more discrete energies. The areas of peaks in the gamma ray spectrum can be related to the quantity of the appropriate radionuclide. Since different isotopes of uranium emit gamma rays of different energies, gamma spectrometry can be used to quantify the relative abundance of uranium isotopes in addition to the total quantity of uranium. Unlike alpha particles, gamma rays can penetrate soil and water, and can be detected some distance from the source.

Instrumental Neutron Activation Analysis (INAA)

INAA involves the irradiation of a sample with neutrons to produce an activation product that decays by emission of gamma rays characteristic of the radionuclide. After irradiation, the sample is counted using a high resolution gamma ray spectrometer. For DU, the radionuclide of interest is ^{238}U, which absorbs a neutron to become ^{239}U. ^{239}U emits gamma radiation when it decays to neptunium-239 (^{239}Np). As mentioned in the previous section, INAA can be used with delayed neutron counting to measure both the isotopic composition and the total quantity of uranium in the sample.

Delayed Neutron Counting (DNC)

DNC is a method for determining the quantity of ^{235}U and other fissile radionuclides in a sample by irradiating the sample with neutrons and counting the delayed neutrons from fission. Delayed neutrons result from a small fraction of fission products that emit neutrons as part of their decay chain. DNC can be used with instrumental neutron activation analysis, described previously, to determine the isotopic composition of uranium, which is necessary to distinguish DU from natural uranium.

Analytical Methods for Air Samples

Air samples are typically collected on some type of air filter and then analyzed by one of the methods described previously, including ICP-MS, alpha spectrometry, or INAA.

In a method used by EPA's National Air and Radiation Environmental Laboratory (NAREL), the air filters are ashed, silica content is volatilized with hydrogen fluoride, uranium is extracted with triisooctylamine, purified by anion exchange chromatography, and co-precipitated with lanthanum as fluoride. The uranium is then collected by filtration and dried. The activities of ^{234}U, ^{235}U, and ^{238}U are measured by alpha spectrometry. This method is used to measure uranium in air as part of the Environmental Radiation Ambient Monitoring System [47].

In another method, described by Singh and Wrenn, air filters are ashed, re-dissolved, and co-precipitated with iron hydroxide and calcium oxalate. The uranium is further purified by solvent extraction and electrodeposition. A detection level of 0.02 dpm /L for ^{238}U in solution was reported using alpha spectrometry [48].

Analytical Methods for Water Samples

EPA's Environmental and Support Laboratory published standardized procedures in 1980 for measurement of radioactivity in drinking water that included uranium analysis by both radiochemical and fluorometric methods [49], and more recently, developed an ICP-MS method.

In the radiochemical method, the uranium is co-precipitated with ferric hydroxide, purified through anion exchange chromatography, and converted to a nitrate salt. The residue is transferred to a stainless steel planchet, dried, and flamed. The gross alpha activity is measured using either a gas flow proportional counter or a scintillation detection system following the chemical separation [49].

For the fluorometric method, uranium is concentrated by co- precipitation with aluminum phosphate, dissolved in diluted nitric acid containing magnesium nitrate as a salting agent, with the co-precipitated uranium extracted into ethyl acetate, and dried. The uranium is dissolved in nitric acid, sodium fluoride flux is added, and the samples fused over a heat source [50].

The ICP-MS method was developed for measuring total uranium in water and waste. The sample preparation is minimal – filtration for dissolved uranium, followed by acid digestion for total recoverable uranium. Recovery is quantitative (near 100%) for a variety of aqueous and solid matrices and detection limits are low, 0.1 :g/L for aqueous samples and 0.05 mg/kg for solid samples [51].

Analytical Methods for Soil Samples

EPA's Office of Radiation and Indoor Air has developed two methods for the radiochemical analysis of uranium in various environmental media including soil: a fusion method and a non-fusion method [47]. In the fusion method, the sample is ashed, the silica volatilized, the sample fused with potassium fluoride and pyrosulphate, a ^{236}U tracer added, and the uranium extracted with triisooctylamine, purified on an anion exchange column, co-precipitated with lanthanum, filtered, and prepared in a planchet. Alpha spectrometry is used to quantify the individual uranium isotopes, and the sample concentration is calculated using the ^{236}U yield.

In the non-fusion method, the sample is ashed, the silica volatilized, a ^{236}U tracer added, and the uranium extracted with triisooctylamine, stripped with nitric acid, co-precipitated with lanthanum, and transferred to a planchet. Further analysis by alpha spectrometry is the same as that for the fusion method.

Table 6: Selected Analytical Methods for Determining Uranium in Environmental Samples
(see Table 6-2 of the Toxicological Profile for Uranium [1] for additional methods and details)

Sample Matrix	Sample Preparation	Analytical Method	Sample Detection Limit	Accuracy
Water	Sample fusion with sodium fluoride (NaF) and lithium fluoride (LiF)	Fluorometry (total uranium)	5 mg/L	117.5% at 6.3 mg/L
Water	Pre-concentration by ion exchange chromatography; purification by ion-exchange and solvent extraction	Neutron Activation Analysis (NAA) (^{235}U and ^{238}U)	No data	No data
Water	Extraction by ion-exchange; dissolution in low oxygen solvent; irradiation	Delayed neutron analysis (total uranium)	0.4 mg/L	No data
Water	Wet-ashed; reaction with complexant	Pulsed-laser phosphorimetry	0.05 ppb	103 (average)
Groundwater	Separation on resin; automated	Flow Injection – Inductively Coupled Plasma – Mass Spectrometry (FI-ICP-MS) (isotope quantification)	0.3 mg/L for ^{238}U	±0.3 ng/L
Groundwater	Separation and concentration on two High Performance Liquid Chromatography (HPLC) columns; complexation with Arsenazo III	Spectrophotometry (total uranium)	1-2 mg/L	No data
Soil	Dissolution in HCl-HNO_3 –HF; purification by co-precipitation, solvent extraction and electrodeposition	Alpha Spectrometry (isotope quantification)	0.03 mg/sample	67%
Soil	Soil leached with HCl-$HclO_4$ –HF; purification by ion exchange, and solvent extraction and electrodeposition	Alpha Spectrometry (isotope quantification)	No data	No data
Soil, sediment, and biota	Ashing; fusion with potassium fluoride (KF) and potassium pyrosulfate ($K_2S_2O_7$); purification by extraction with triisooctylamine; anion exchange chromatography and co-precipitation	Alpha Spectrometry	No data	No data
Soil, sediment, and biota	Ashing; extraction into triisooctylamine, strip from triisooctylamine with nitric acid (HNO_3), and coprecipitation with lanthanum.	Gross Alpha Spectrometry or Alpha Spectrometry	No data	No data

Sample Matrix	Sample Preparation	Analytical Method	Sample Detection Limit	Accuracy
Field Survey	None	Scintillation Detector and Count Rate Meter		No data
Air	Air particulate collection on glass fiber filter, digestion in nitric acid (HNO_3)	Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) (total uranium)	0.1 mg/L in final solution	No data
Air	Spiked air particulate dry and wet ashed; dissolution; coprecipitation with iron hydroxide and Ca oxalate, purification by solvent extraction and electrodeposition onto platinum	Alpha Spectrometry	0.02 dpm/L for ^{238}U in solution	No data
Air	Sample collection on cellulose filters; ashing; extraction with triisooctylamine; purification by anion exchange chromatography and co-precipitation	Alpha Spectrometry	0.015 pCi	No data
Air	Collection on cellulose filters	Instrumental Neutron Activation Analysis (INAA)	0.03 mg per filter	No data

Source: Toxicological Report for Uranium [1], Table 6-2

Appendix 3: National Priorities List (NPL) Sites that have or may have DU Contamination

NPL Site	EPA Region	Description
Maxey Flats Nuclear Disposal, Hillsboro, Kentucky (NPL-1986)	Region 4	The Maxey Flats Nuclear Disposal Site is located in eastern Kentucky near Hillsboro in Fleming County and was a disposal facility for low-level radioactive waste. Approximately 533,000 pounds of source material (consisting of uranium and thorium or ores containing them), 2.5 megacuries (MCi) of byproduct materials, and 950 pounds of special nuclear material (i.e., plutonium and enriched uranium) were buried in an area known as the Restricted Area. Radioactive leachate was discovered to be leaching out of this area and into surrounding fractured bedrock, soil, and possibly groundwater. The remediation approach was to capture and evaporate the leachate, producing solid concentrates that were then buried in onsite disposal trenches, which were ultimately capped. Other liquid waste was solidified and buried in another onsite disposal trench, which was also capped.
Malta Rocket Fuel Area, Malta, New York (NPL-1987)	Region 2	This site is located in the towns of Malta and Stillwater, New York, approximately 1 mile south of Saratoga Lake and 2 miles northeast of Round Lake. All or part of the Test Station on the site has been leased and used for a wide range of rocket and weapons testing programs and for space and other research. In 1979, approximately 8 grams of uranium hexafluoride gas were released in a portion of the former GE/Exxon nuclear building. The area was cleaned and the contaminated material was sent to licensed disposal facilities.
Savannah River Site, Aiken, South Carolina (NPL-1989)	Region 4	Savannah River has produced nuclear materials for national defense since 1951. This site is surrounded by woods and ranges from dry hilltops to swampland. The Department of Energy (DOE) reports that a small quantity of DU was released in January 1984 into Upper Three Runs Creek, which eventually flows into the Savannah River. The site remedy has included groundwater pump and treat, capping/solidification of various disposal basins and solid waste disposal sites, removal and treatment and/or disposal of hazardous substances, and shipping process waste to the Waste Isolation Pilot Project in New Mexico.
Rocky Flats Environmental Technology Site, Golden, Colorado (NPL-1989)	Region 8	This former plant manufactured plutonium components for nuclear weapons and shut down operations in 1989 in response to alleged violations of environmental statutes. In 1992, the United States decided not to resume production at this site. During the summer of 1998, DOE excavated 171 drums of uranium and contaminated soil from Trench T-1. Most of this waste was shipped to the Nevada Test Site for disposal.
Oak Ridge Reservation (DOE), Oak Ridge, Tennessee (NPL-1989)	Region 4	Two facilities at this site produced enriched uranium: the Y-12 plant by an electromagnetic process, and the K-25 plant by gaseous diffusion. DU is a byproduct of both of these processes. There has been leakage from this site into the surrounding environment. At the Y-12 plant, the Abandoned Nitric Acid Pipeline was used to carry waste effluent, which included DU.
Iowa Army Ammunition Plant, Des Moines County, Iowa (NPL-1990)	Region 7	The Iowa Army Ammunition Plant site's primary activity has been to load, assemble, and pack a variety of conventional ammunition and fusing systems. In the fall of 2000, chunks of DU were reported at the Firing Site. This has prompted increased focus on the site.

NPL Site	EPA Region	Description
Naval Surface Warfare Center, Dahlgren, Virginia (NPL-1992)	Region 3	NSWC is approximately 4,300 acres and located 40 miles south of Washington, D. C., along the Potomac River. This site conducts research, development, testing, and evaluation of surface ship weaponry. Six sites are related to the former use of munitions, some of which included DU.
Materials Technology Laboratory (U.S. Army), Watertown, Massachusetts (NPL-1994)	Region 1	Located on 48 acres of land on the north bank of the Charles River, this arsenal has been in operation since 1816. In addition to storage, this facility has expanded into weapons development and production. Specifically, DU machining, milling, forging, and casting took place on this site. Radiological contamination present at the site has been remediated and removed. At the time of this writing, the site's remediation focus is on decontaminating the soil.
Gaseous Diffusion Plant (USEC), Paducah, Kentucky (NPL-1994)	Region 4	This site, which is 3 miles south of the Ohio River and 10 miles west of Paducah, KY, performed the first step in the uranium-enrichment process. Separating the uranium by diffusing it through a barrier results in several end products, one of which is DU. Radiological and volatile organic compound (VOC) contamination has been found in on- and offsite wells, and polychlorinated biphenyl (PCBs) in offsite surface water bodies.
Nuclear Metals, Concord, Massachusetts (NPL-2001)	Region 1	The Nuclear Metals, Inc., also known as Starmet Corporation, site is located in Concord, Massachusetts. In 1958, NMI began operating a manufacturing facility that produced DU products, primarily as penetrators for armor piercing ammunition. Soil, sediment, and surface water samples taken historically and recently indicate that the holding basin, sphagnum bog, and cooling recharge pond all have elevated levels of DU.

Appendix 4: Facilities Involved with the Manufacturing or Testing of Products Containing DU and/or Components of Products Containing DU**

Facility/Site/Company Name	Location	EPA Region
Sierra Army Weapons Depot	Susanville, California	Region 9
Aerojet Ordinance Company	Downy, California	Region 9
NI Industries	Los Angeles, California	Region 9
Hughes Helicopter	Los Angeles, California	Region 9
Armtec Defense Products	Coachella, California	Region 3
China Lake Naval Weapons Center	China Lake, California	Region 3
Elgin Air Force Base Munition Test Facility	Valpariso, Florida	Region 4
Chamberlain	Waterloo, Iowa	Region 7
Mason & Hangar	Middletown, Iowa	Region 7
Specific Manufacturing Capability, INEEL	Idaho Falls, Idaho	Region 10
U.S. Army Armament Munitions & Chemical Compound	Rock Island, Illinois	Region 5
Olin Corporation	East Alton, Illinois	Region 5
Jefferson Proving Ground, U.S. Army	Madison, Indiana	Region 5
U.S. Army	Fort Riley, Kansas	Region 7
Paducah Gaseous Diffusion Plant, U.S. DOE	Paducah, Kentucky	Region 4
Nuclear Metal, Inc.	Concord, Massachusetts	Region 1
U.S. Army Laboratory Command	Watertown, Massachusetts	Region 1
Chamberlain	New Bedford, Massachusetts	Region 1
U.S. Army Aberdeen Proving Ground	Aberdeen, Maryland	Region 3
General Dynamics	Detroit, Michigan	Region 5
U.S. Army Camp Grayling	Grayling, Michigan	Region 5
Honeywell	Minnetonka, Minnesota	Region 5
Honeywell Corporation	Hopkins, Minnesota	Region 5
U.S. Army Twin Cities Army Ammunition Plant	New Brighton, Minnesota	Region 5
Kisco	St. Louis, Missouri	Region 7
Remington Arms Company Lake City Army Ammunition Plant	Independence, Missouri	Region 7
Target Research, Inc.	Dover, New Jersey	Region 2
Los Alamos National Laboratory	Los Alamos, New Mexico	Region 6
Los Alamos, New Mexico	Albuquerque, New Mexico	Region 6
Kirkland Air Force Base	Albuquerque, New Mexico	Region 6
Terminal Effects Research and Analysis	Socorro, New Mexico	Region 6
Aerojet General Corporation	Lockwood, Nevada	Region 9
U.S. Ecology	Beatty, Nevada	Region 9
U.S. Army Ballistics Research Laboratory, Nevada Test Site	Mercury, Nevada	Region 9
Nellis Air Force Base	Las Vegas, Nevada	Region 9
National Lead Industries	Colonie, New York	Region 2
Watervliet Arsenal	Albany, New York	Region 2
Bulova Systems	Valley Stream, New York	Region 2
Lima Army Tank Plant, General Dynamics	Lima, Ohio	Region 5
Feed Materials Plant, U.S. DOE	Fernald, Ohio	Region 5
Portsmouth Uranium Enrichment Plant, U.S. DOE	Portsmouth, Ohio	Region 5
Ashtabula Extrusion Plant	Ashtabula, Ohio	Region 5
Sequoyah Fuel Corporation	Gore, Oklahoma	Region 6
General Defense	Red Lion, Pennsylvania	Region 3
Carolina Metals	Barnwell, South Carolina	Region 4
Savannah River Site, DOE	Aiken, South Carolina	Region 4
Defense Consolidation Facility	Snelling, South Carolina	Region 4
Aerojet Heavy Metals	Jonesboro, Tennessee	Region 4
Martin Marietta Energy Systems K-25 Site*	Oak Ridge, Tennessee	Region 4
Day and Zimmerman	Texarkana, Texas	Region 6
Pantex Plant, U.S. DOE	Amarillo, Texas	Region 6
General Dynamics	Falls Church, Virginia	Region 3
U.S. Naval Surface Weapons Center	Dahlgren, Virginia	Region 3

Facility/Site/Company Name	Location	EPA Region
Hercules	Radford, Virginia	Region 3
Ethan Allen Firing Range General Electric	Burlington, Vermont	Region 1
Hanford Nuclear Reservation, U.S. DOE	Hanford, Washington	Region 10
U.S. Army Yakima Firing Range	Yakima, Washington	Region 10
Stresau Labs	Spooner, Wisconsin	Region 5

* The Martin Marietta Energy Systems K-25 facility is now known as the East Tennessee Technology Park; it was originally known as the Oak Ridge Gaseous Diffusion Plant.

** This list includes the locations and names of facilities involved in the manufacturing and/or testing of components that were eventually incorporated into a product containing Depleted Uranium (DU). Inclusion on this list does not imply that DU was undeniably present at the facility, but only denotes that the listed facility was part of the manufacturing or testing process of some aspect of a product containing DU. In a few cases, the components produced at the listed facility did not contain DU at that point of the process.

Appendix 5: Case Study - Nuclear Metals, Inc. (NMI) site, Concord, Massachusetts

Background

The Nuclear Metals, Inc. (NMI) site, also known as the Starmet Corporation site, is located on a 46.4-acre parcel located at 2229 Main Street in Concord, Middlesex County, Massachusetts. The facility includes five interconnected buildings, a paved parking area, a sphagnum bog, a cooling water recharge pond, and a holding basin.

In 1958, NMI began operating a manufacturing facility on previously undeveloped land. Nuclear Metals, Inc. produced DU products, primarily as penetrators for armor piercing ammunition. NMI also manufactured metal powders for medical applications, photocopiers, and specialty metal products Disposal was executed via waste stream discharge. From 1958 to 1985, NMI discharged wastes to an unlined holding basin. Extrusion operations on depleted uranium produced rods with a thin layer of copper coating that was removed in a nitric acid pickling operation during which "small quantities" of copper and uranium were dissolved in the nitric acid. The spent nitric acid solution was collected, neutralized with a lime slurry, and discharged to the unlined, in-ground holding basin along with other wastes. Discharge to the holding basin ceased in 1985 when NMI began using an acid closed-loop recycling process.

NMI was renamed Starmet Corporation in 1997. In March 1997, the company's NRC license to handle source material (including depleted uranium, thorium, and thorium oxide) was transferred to the Massachusetts Department of Public Health, Radiation Control Program. The state collected groundwater samples and detected volatile organic compounds (VOCs) in NMI's supply well, previously used for drinking water. Further analytical results indicated that the groundwater beneath the property was contaminated with radionuclides (i.e., uranium and thorium), and other materials. In addition, a sphagnum bog on the property was also been sampled and has shown evidence of radionuclides. Soil, sediment, and surface water samples taken historically and recently indicated that the holding basin, sphagnum bog, and the cooling water recharge pond all have exhibited elevated levels of depleted uranium.

Cleanup Approach

In 1998, Starmet conducted a voluntary partial cleanup of contaminated soils under the Massachusetts Department of Environmental Protection (MADEP) oversight. The partial cleanup consisted of excavation and transportation off-site of approximately 8,000 cubic yards of soil contaminated with depleted uranium and copper. The cleanup halted in late 1998 when Starmet determined that the cleanup level set by MADEP could not be met without excavation of a significantly greater quantity of material. The site has since been listed on the National Priorities List; further evaluation of remaining contamination at the site will be addressed under EPA authority.

Response Action

A time-critical removal assessment was conducted to determine if buried drums on site contain hazardous material. Two areas containing buried drums and other laboratory equipment were located during the removal assessment: one in a fenced-in area adjacent to the holding basin and cooling water pond, and contains approximately 70 drums; the other, called the "old landfill" contains an unknown number of drums and laboratory equipment. A time-critical removal action was conducted which included: 1) installation of fencing around the "old landfill" area where buried drums are located; 2) re-grading and capping of the "old landfill" area; and 3) installation of a liner in the holding basin to eliminate fugitive dust and reduce the leaching of contaminated soils into the groundwater. Sampling and analysis of soils in the holding basin was conducted in September 2001 to fill data gaps in previous sampling efforts and to determine if data from past sampling efforts performed by Starmet were comparable to EPA data. In June 2002, EPA assumed the groundwater monitoring program previously performed by Starmet. During the

June 2002 sampling event, EPA also sampled sediment and surface water on-site and in the Assabet River. EPA sampled the groundwater monitoring wells again in July 2003 before turning site work over to Potentially Responsible Parties.

Progress and Current Status

Removal of 8,000 cubic yards of soil from the holding basin by Starmet under MADEP oversight has reduced the threat of potential exposure at the site. A time-critical removal action has been conducted to prevent the direct contact threat with the contaminated surface soils located in the "old landfill" area, and to reduce the infiltration of precipitation into the holding basin soils. EPA has installed a fence and warning signs around the perimeter of contaminated soils in the " old landfill" area, has capped the "old landfill" area; and, has installed a liner over the holding basin. In June 2003, EPA also negotiated an agreement with five potentially responsible parties including: U.S. Army, U.S. DOE, Whittaker Corporation, MONY Life Insurance Co., and Textron, Incorporated, for the performance of a Remedial Investigation/Feasibility Study (RI/FS), which includes the performance of an Engineering Evaluation and Cost Analysis (EE/CA). An EE/CA Approval Memorandum was signed on September 27, 2002, which authorizes the performance of an EE/CA in support of a Non Time-Critical Removal Action for the holding basin and buried drum areas. A lien has been recorded on the Starmet property at 2229 Main Street in Concord.

In May 2001, Starmet transported 1,700 drums containing depleted uranium from its South Carolina facility to the site, to facilitate its planned sale of that facility. Starmet also has approximately 2000 drums and other containers of depleted uranium wastes and approximately 100 drums of beryllium wastes stored at the site. Starmet is currently in violation of its MADPH radio active materials license because it has failed to remove the stored drums of depleted uranium materials from the site and is therefore not allowed to process any radioactive material at the facility under their license. After Starmet indicated that it planned to cease operations or file for bankruptcy, the Commonwealth of Massachusetts obtained a preliminary injunction in state court in January 2002, requiring Starmet to continue to provide site security and necessary utilities. On March 15, 2002, the state court placed Starmet into temporary receivership. On or about March 18, 2002, Starmet abandoned the site property. The temporary receiver provided security and necessary utilities, with the assistance of MADPH, until March 25, 2002. Thereafter, MADPH began providing security at the site. Starmet filed for Chapter 11 bankruptcy protection on April 3, 2002, returned to the site, and continues to operate and provide site security. MADPH currently has funding available to provide security and necessary utilities if needed, through the financial assurance mechanism provided under Starmet's radioactive materials license. If MADPH's funding is exhausted and no other funding source is available, resulting in abandonment of the facility, then EPA may be required to address the security and utilities issues.

In April 2004, the state reached an agreement with the Army to remove the more than 3,000 drums of depleted uranium and other materials from within the facility. The state has procured a contractor for performance of the work, and shipments of drums and other material to the Envirocare waste disposal facility in Clive, Utah, began in September 2005. It is expected that the state removal work will be completed in spring 2006. In September 2004, EPA conditionally approved the RI/FS Work Plan submitted by de maxi mis, inc., the project coordinator for the private PRPs. Field work associated with the remedial investigation began in October 2004. In October 2004, under the supervision of U.S. Environmental Protection Agency, de maximis, inc., started an investigation of the Superfund Site to locate all contaminants and prepare a feasibility study of the Site cleanup. So far over 1300 samples of soil, sediment and water have been collected and analyzed. Since each sample is analyzed for a number of different contaminants, the data base contains over 300,000 records. Soil contamination has been found at several locations on the site. Contamination has also been located in the groundwater. The major contaminant is uranium. Polychlorinated biphenyls (PCBs) and volatile organic compounds are also present. A number of other chemicals have been detected at lower concentrations. Analysis of data is being conducted to determine the extent of, and the risk from, the contamination.

Under a contract with MA DEP, Envirocare Inc. is removing all identifiable radioactive and other waste material from the Starmet Plant. The material shipped so far to Clive, Utah, includes 1,315 drums of uranium tetrafluoride, 1,097 drums of a concrete and uranium mixture (conjoint) and 447 drums of other uranium waste. Approximately 250 drums of uranium tetrafluoride, 200 tons of uranium metal, and other miscellaneous waste remain to be shipped. The material is removed every working day in two or three Landstar Co. tractor trailers. The work was scheduled for completion by March 31, 2006. Removal of the radioactive material is required prior to starting the EPA investigation of the buildings and soil and water beneath them. The funding for the contract was provided by the U.S. Army.

In December 2004, de maximis, inc., under supervision of the EPA, removed from the ground between the Holding Basin and Cooling Water Recharge Pond a number of drums containing some uranium and beryllium waste, production tools and production materials, buried in 1967.

In April 2003 Weston Solutions Inc., under a contract with EPA, removed from the ground in the area of the Old Landfill (south of Bog) drums containing uranium and beryllium, more production tools and materials, then filled, graded and covered the area. Another phase of the plant cleanup, which will include the removal of all contaminated equipment, is anticipated after Starmet leaves the premises.

Further Information

- http://yosemite.epa.gov/r1/npl_pad.nsf/f52fa5c31faf5c885256adc0050b631/7B6349F1A22FFDF385259E5006CA840?OpenDocument
- http://www.crewconcord.org/pages/whats_new.html

Appendix 6: Case Study - Maxey Flats Nuclear Disposal Site, Hillsboro, Kentucky

Background

The Maxey Flats Nuclear Disposal Site is located in eastern Kentucky, near Hillsboro, in Fleming County. The site was a disposal facility for low-level radioactive wastes. The site is located on a spur of Maxey Flats, a ridge 300 feet above the surrounding stream valleys. The area surrounding the site is rural and agricultural. More than 300 people live within a five mile radius of the restricted area; the closest residence is within ¼ mile. More than 120 wells and 25 springs are situated within five miles; however, nearby residents receive household water from a municipal water system.

From 1963 to 1977, the Commonwealth of Kentucky, under authorities granted by the U.S. Government, licensed private operators including the Nuclear Engineering Company (NECO) to dispose of low-level radioactive wastes from military ships and facilities, hospitals, universities, corporations, etc.; an estimated five million cubic feet of material were disposed. Most was solid waste; however, other waste types were disposed and some were highly radioactive. Approximately 533,000 pounds of source material (consisting of uranium and thorium or ores containing them), 2.5 megacuries (MCi) of byproduct materials, and 950 pounds of special nuclear material (plutonium and enriched uranium) were buried in an area known as the Restricted Area.

Between 1973 and 1986 a large evaporator facility was operated on site to handle contaminated liquids. During the operation of the facility , workers capped each disposal trench with a layer of soil after it was filled, but the earth eventually collapsed into the ditches. Water collected in the trenches, leaching radionuclides into the surrounding environment. A restricted area of approximately 40 acres is situated entirely on top of the flats. The fenced and patrolled restricted area encompasses the disposal trenches, "hot wells" (sealed concrete pipes containing plutonium and uranium), waste storage buildings, and an evaporator facility. Including the acquired buffer zone properties, the site occupies 900 acres.

Operations closed in 1973 and by 1985, the U.S. EPA had developed a list of potentially responsible parties (PRPs) from the disposal records toward whom to point financial responsibility. In 1986 Maxey Flats was placed on the National Priorities List, becoming, at 300 acres, one of the largest Superfund sites in the history of the program, and from 1987 to 1991 extensive studies on remediation options were carried out.

Response Action

To assure proper management and closure, the Commonwealth of Kentucky has maintained the site since the time that commercial operations ended. The Remedial Investigation and Feasibility Study was conducted from March, 1987 until September, 1991 under an administrative Order by Consent. The Record of Decision was issued in September, 1991. Meanwhile, between December, 1988 and November, 1989, U.S. EPA Emergency Response solidified 286,000 gallons of tanked leachate because of significant leakage from the metal leachate (radioactively contaminated trench water) tanks. Subsequently, from March, 1991 to September, 1992, U.S. EPA Emergency Response disposed of the solidified leachate blocks in an underground on-site trench and installed 30 acres of temporary above-ground plastic, impermeable liner to prevent infiltration of rain into the waste trenches.

After negotiations lasting from June, 1992 until June, 1995, two Consent Decrees (one for the 50 de maximis parties and one for the 306 de minimis parties) arranged for cost allocation and for the performance of the Remedial Design (RD) and Remedial Action. After the required public comment periods, the U.S. District Court activated the decrees in April 1996; the RD for the first of two major cleanup phases (1. Leachate Removal and Disposal; 2. Building Demolition, On-Site Disposal, and Other Items) began immediately thereafter. Construction of Phase I and Phase II of the reinforced concrete bunkers (for disposal of solidified radioactive leachate and other contaminated materials) have been completed.

Approximately 900,000 gallons of leachate and have been removed from within the landfill since current dewatering operations began in September, 1998. However, the median total daily volumes of water removed declined from more than 5,050 gallons in 1998 to less than 600 gallons during the 2000 pumping season. Landfill dewatering operations were discontinued during the early fall of 2000. Construction of an interim cap to prevent water infiltration with a perimeter drainage system that includes the groundwater interceptor channel has been completed. To verify the drainage system does not negatively impact erosion rates, erosion monuments have been installed for monitoring the rate of erosion.

The completion of the Initial Remedial Phase was declared in October 2003 by U.S. EPA. Remedial work completed at the Maxey Flats Waste Disposal Site has been under the guidance of the U.S. EPA, Atlanta, Georgia, and in accordance with the Consent Decree signed in 1996. International Technology Corporation and Shaw Environmental Group performed the remedial construction.

Progress and Current Status

A five year review was completed in 2002; other five year reviews are planned for 2007 and 2012, the latter of which, if successful, will render the Commonwealth of Kentucky fully responsible for the site. Corrective steps completed in 2003 have brought most problems at the site under control. The steps include installation of the geomembrane liner, which directs rainwater into a detention basin to be tested for radioactivity before it is released into a nearby creek. Contaminated water was pumped out of the storage trenches, solidified with concrete, and buried on site. Automatic monitoring equipment samples surface water at multiple locations around the site every six hours for testing. A 550-acre "buffer zone" has been added around the perimeter of the site to separate it from the surrounding farms and homes.

No contaminated water has been found outside Maxey Flats' restricted area, with the exception of two springs in the buffer zone where low levels have been detected. If work continues on schedule, a permanent "cap" consisting of multiple layers of liner and soil, with grass sown on the surface, is planned to cover the site sometime around 2012. The total cost of cleanup and monitoring is expected to exceed $60 million. In addition to the depleted uranium contamination, Maxey Flats is also noted for tritium, strontium-90, and radium-226 contamination.

Further Information

- http://www.waste.ky.gov/programs/sf/Maxey+Flats.htm
- http://www.epa.gov/Region4/waste/npl/nplky/maxfltky.htm
- http://nucnews.net/nucnews/2006nn/0604nn/060423nn.txt

Appendix 7: Treatment Defined by NCP

The concept of treatment is discussed in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) under Section 300.5, as follows:

> “Treatment technology” means any unit operation or series of unit operations that alters the composition of a hazardous substance, pollutant, or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated materials being treated. Treatment technologies are an alternative to land disposal of hazardous wastes without treatment.

The NCP further states that

> “EPA expects to use treatment to address the principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.” (See Section 300.430 (a)(iii)(A))

The preamble to the NCP provides further clarification of treatment:

> “This goal [treatment expectation] reflects CERCLA’s preference for achieving protection through the use of treatment technologies that destroy or reduce the inherent hazards posed by wastes and result in remedies that are highly reliable over time. The purpose of treatment in the Superfund program is to significantly reduce the toxicity and/or mobility of the contaminants posing a significant threat (i.e., “contaminants of concern”) wherever practicable to reduce the need for long-term management of hazardous material. EPA will seek to reduce hazards (i.e., toxicity and/or mobility) to levels that ensure that contaminated material remaining on-site can be reliably controlled over time through engineering and/or institutional controls.
>
> Further, the Superfund program also uses as a guideline for effective treatment the range of 90 to 99 percent reduction in the concentration or mobility of contaminants of concern (see preamble discussion below on “reduction of toxicity, mobility or volume” under Section 300.430 (e)(9)). Although it is most important that treatment technologies achieve the remediation goals developed specifically for each site (which may be greater or less than the treatment guidelines), EPA believes that, in general, treatment technologies or treatment trains that cannot achieve this level of performance on a consistent basis are not sufficiently effective and generally will not be appropriate. [See 55 FR 8701]

For further information on this definition please contact EPA’s Office of Superfund Remediation & Technology Innovation.

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