THESIS

URANIUM CONTAMINATION VALUES AND LIMITS

Submitted by

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ABSTRACT

URANIUM CONTAMINATION VALUES AND LIMITS

Hypothesis:

Current soil contamination limits for non-enriched uranium are not consistent and are not optimized to allow the beneficial use of uranium while protecting the health of the public.

Objective:

Assess available health impact data regarding non-enriched uranium ingestion and inhalation as well as past soil contamination recommendations to determine if the regulatory limits for uranium are optimized, as recommended by the ICRP. Provide supporting data for keeping current soil contamination limits for non-enriched uranium, or suggest new limits based upon chemical uptake ratios.

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ACRONYMS, ABBREVIATIONS AND DEFINITIONS

α	Alpha particle
Accelerator Produced Radioactive Material	Radioactive material produced as the result of operating a particle accelerator.
ACGIH	American Conference of Industrial Hygienists
AEA	Atomic Energy Act of 1954, as amended
AEC	Atomic Energy Commission
AFL/CIO	American Federation of Labor and Congress of Industrial Organizations, a national trade union
Agreement State	Any state, territory, or possession of the United States that, by agreement with the NRC, has assumed regulatory authority over byproduct, source, and certain small quantities of special nuclear material.
ALARA	As Low As Reasonably Achievable
ALI	Annual limit on intake
AMAD	Activity Median Aerodynamic Diameter
Annual	Recurring, done, or performed every year (i.e. every 12 months).
Annual Limit on Intake	The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year
Anorexia	Loss of appetite and inability to eat
ANSI	American National Standards Institute
AOC	Area of Concern
ARC	Alternate Release Criteria
AFRRI	Armed Forces Radiobiology Research Institute
As Low As Reasonably Achievable	A principle of radiation protection philosophy that requires that exposures to ionizing radiation be kept as low as reasonably achievable, economic and social factors being taken into account. The protection from radiation exposure is ALARA when the expenditure of further resources would be unwarranted by the reduction in exposure that would be achieved.
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR reports	Biological Effects of Ionizing Radiation Report

BKG	Background
Carnotite	An uranium-vanadate ore
CDE	Committed dose equivalent
CEDE	Committed effective dose equivalent
CFR	Code of Federal Regulations
Class D	Clearance half-times of less than 10 days.
Class W	Clearance half-times of 10 to 100 days
Class Y	Clearance half-time of over 100 days
Coffinate	An uranium silicate, a common uranium ore.
Concentration Ratio	Ratio of uranium in the leaves of plants eaten by herbivores or omnivores (usually 10%)
cpm	counts per minute
CR	Concentration Ratio
Creatinine	A useful biomarker for depleted uranium uptake
D&D	Decontamination and decommissioning
DAC	Derived air concentration
DCGL	Derived concentration guideline level
DCGL (EMC)	DCGL (Elevated Measurement Comparison). Used for small areas of elevated activity
DCGL(w)	DCGL (weighted). Used for average concentrations over a wide area
DF	Dose factor
DoD	Department of Defense
DOE	Department of Energy
DOL	Department of Labor
DOT	Department of Transportation
DP	Decommissioning Plan
DU	Depleted uranium
EMC	Elevated measurement comparison
Environmental Protection Agency	The mission of Environmental Protection Agency (EPA) is to protect human health and the environment
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency

Flesh to Whole Body Ratio	The concentration of uranium in the flesh (not bones) to the concentration of uranium in the whole body
FUSRAP	Formally utilized site remedial action plan sites
FWB	Flesh to Whole Body Ratio
HP	Health physics
HQAPP	Hematite Quality Assurance Program Plan
Human Uptake Ratio	Ratio of uranium taken in by humans from eating uranium from normal food
HUR	Human Uptake Ratio
I.D.	Identification
ICP/MS	Inductively Coupled Plasma/Mass Spectrometry. The most useful method for determining DU uptake.
ICRP	The International Commission on Radiological Protection (ICRP) is an advisory body providing recommendations and guidance on radiation protection
ICRU	International Commission on Radiation Units and Measurements
JPG	Jefferson Proving Ground
Kidney	The organ in mammals that regulates electrolyte, blood pressure and pH balance in the body as well as filtering the blood and removing waste products.
License	Written authorization from the NRC or an Agreement State to acquire, receive, use, store or transfer byproduct, source, or special nuclear material.
Lowest Observed Adverse Effect Level	LOAEL is the lowest experimentally tested dose of a substance that has been reported to cause adverse health effects.
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provides guidance to federal agencies, states, site owners, contractors, and other private entities on how to demonstrate that their site is in compliance with a radiation dose or risk-based regulation, otherwise known as a release criterion
MDC	Minimum Detectable Concentration
mrem/yr	millirem per year
mSv	Millisievert
National Drinking Water Standard	National Primary Drinking Water Regulations (NPDWRs or primary standards) are the EPA's legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water

NCRP	National Council on Radiation Protection and Measurements
Nephrotoxic	Damaging to the kidneys
NIST	National Institute of Standards and Technology
NPDWR	National Primary Drinking Water Regulations
NRC	Nuclear Regulatory Commission
Nuclear Regulatory Commission	An agency established by Title II of the Energy Reorganization Act of 1974 (Public Law 93-438) to regulate byproduct, source, and special nuclear material as provided for by the Atomic Energy Act of 1954, as amended. Within the NRC, final authority rests with the five member Commission acting as a body.
NUREG	Technical reports on various topics related to the regulation of nuclear energy published by Nuclear Regulatory Commission.
Occupational Safety and Health Administration	With the Occupational Safety and Health Act of 1970, Congress created the Occupational Safety and Health Administration (OSHA) to assure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance.
OSHA	Occupational Safety and Health Administration
pCi/g	picocuries per gram. Approximately 27.1 pCi/g equals 1 Bq/g.
PEL	Permitted Exposure Limit. OSHA- enforceable limits on the magnitude and duration of employee exposure to each contaminant. The amount of exposure permitted by a given PEL depends on the toxicity and other characteristics of the particular substance.
PHC	Public Health Command. PHC's mission is to promote health and prevent disease, injury, and disability of Soldiers and military retirees, their Families, and Department of the Army civilian employees; and assure effective execution of full spectrum veterinary service for Army and Department of Defense Veterinary missions
Pitchblende	A form of uraninite, an uranium oxide, a common uranium ore.
PNNL	Pacific Northwest National Laboratory
ppm	Parts per million is equal to mg/kg.
Radon-222	Daughter of radium-226, a decay product of uranium-238
RCRA	Resource Conservation and Recovery Act

RESRAD	RESRAD is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials
SC	Soil Concentration
Sodium bicarbonate	(1) The leachate used for in-situ leach mining of uranium ores. (2) Antacid taken orally to treat acid indigestion. (3) Sodium bicarbonate can protect the kidney from damage in a uranium overdose situation (NCRP-65).
Soil Concentration	Concentration of uranium in the soil
TF	Transfer Fraction
Transfer Fraction	The ratio of uptake of uranium by the plant to the concentration of uranium in the soil
TRIGA Reactor	TRIGA (Training, Research, Isotopes, General Atomics) Reactors are non-power reactors used by universities, government and industrial laboratories, and medical centers worldwide
U-234	Uranium-234
U-235	Uranium-235
U-236	Uranium-236
U-238	Uranium-238
UF_6	Uranium hexafluoride
U-nat	Uranium (natural)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
Uraninite	An uranium oxide, a common uranium ore.
Uranium (natural)	99.274% U-238, 0.72% U-235 and 0.0057% U-234, by weight.
Uranium (ore)	1000 mg Uranium / kg of ore is the minimum concentration of uranium that is considered useable for the uranium industry
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine, now known as Public Health Command (PHC) and formally known as Army Industrial Hygiene Laboratory (AIHL) and United States Army Environmental Hygiene Agency (USAEHA).
U-total	Total uranium
West Valley Demonstration Project	West Valley Demonstration Project (WVDP) is former nuclear fuel reprocessing station

EXECUTIVE SUMMARY

It is important for the health physics community to reach out worldwide and enlist the aid of the toxicologists, chemists, biochemists, agriculture specialists, medical doctors and veterinarians in determining how to regulate the chemical hazards of the various uranium chemicals. Uranium is far more than radiological dose, and a broad-based approach to this complicated system of chemicals is warranted.

The current uranium limits could be revisited and revised based upon the various uranium chemical and their varying chemical uptake ratios. The availability for incorporation in to tissues upon consumption (uptake) could be based upon the chemical form (Table 1) but more human use data is warranted before these alternate release criteria (ARC) could be used.

The ARC in Table 1 is based upon a small data set regarding uptake ratios in animals. The significant human uranium toxicity data was variable.

Table 1, Chemically based Alternate Release Criteria for Non-enriched Uranium Compounds

	pCi U-238 per gram at the site		
	Agricultural / Garden	Public Access	Industrial
$UO_2(NO_3)_2$ $6H_2O$	3.9×10^1	1.0×10^2	3.9×10^2
UO_2F_2	3.9×10^1	1.0×10^2	3.9×10^2
$Na_2U_2O_7$	3.9×10^1	1.0×10^2	3.9×10^2
UO_4	7.8×10^1	2.0×10^2	7.8×10^2
UO_3	7.8×10^1	2.0×10^2	7.8×10^2
U-nat	1.3×10^2	3.4×10^2	1.3×10^3
DU	1.3×10^2	3.4×10^2	1.3×10^3
UCl_4	3.9×10^2	1.0×10^3	3.9×10^3
UO_2	3.9×10^2	1.0×10^3	3.9×10^3
UF_4	2.0×10^3	5.0×10^3	2.0×10^4
U_3O_8	3.9×10^3	1.0×10^4	3.9×10^4

Supporting criteria:

1. Human Health: No biological impact due to natural uranium was found in an extensive literature search. The data in Table 1 are based upon agricultural areas with high natural uranium (Al-Kharouf, et al, 2008) and the intake fractions from the various uranium compounds used in animal models (Leggett and Harrison, 1995). No significant human use data regarding uranium was available to give a definitive toxicity recommendation.
2. Cost: Changing from a 30 pCi/g (1.1 Bq/g) limit in soil to 130 pCi/g (4.8 Bq/g) could save the US taxpayers $4.5 billion to $12.0 billion.
3. Legal: Regulatory agencies are required to provide evidence to support limits. The evidence compiled for this study demonstrate that there is a limited human health hazard from uranium in soils that appears to manifest at concentrations significantly above some of the currently utilized limits.

Considering the low numbers of human toxicity data, it could be argued that no limits should be imposed. Changing to a no-limit level could cause social concern among the public, so the ARC values based upon chemical uptake in animal models have been suggested as a compromise. The ALARA principle factors in social concerns as well as health and economic concerns, and while the pure scientific data might support higher limits, the view of the general public should not be discounted.

The NRC ADAMS documents yielded 38K data points on limits and values for both enriched and non-enriched uranium. This data can be conclusively shown to prove that limits and values vary by orders of magnitude (Figure 1). The non-enriched uranium limits utilized by the NRC at all locations monitored by the NRC (uranium mines, uranium mills, DU firing ranges, hospitals, nuclear power plants, and uranium enrichment sites for the past 30 + years, span six orders of magnitude and the actual number of limits increases with time (Figure 1).

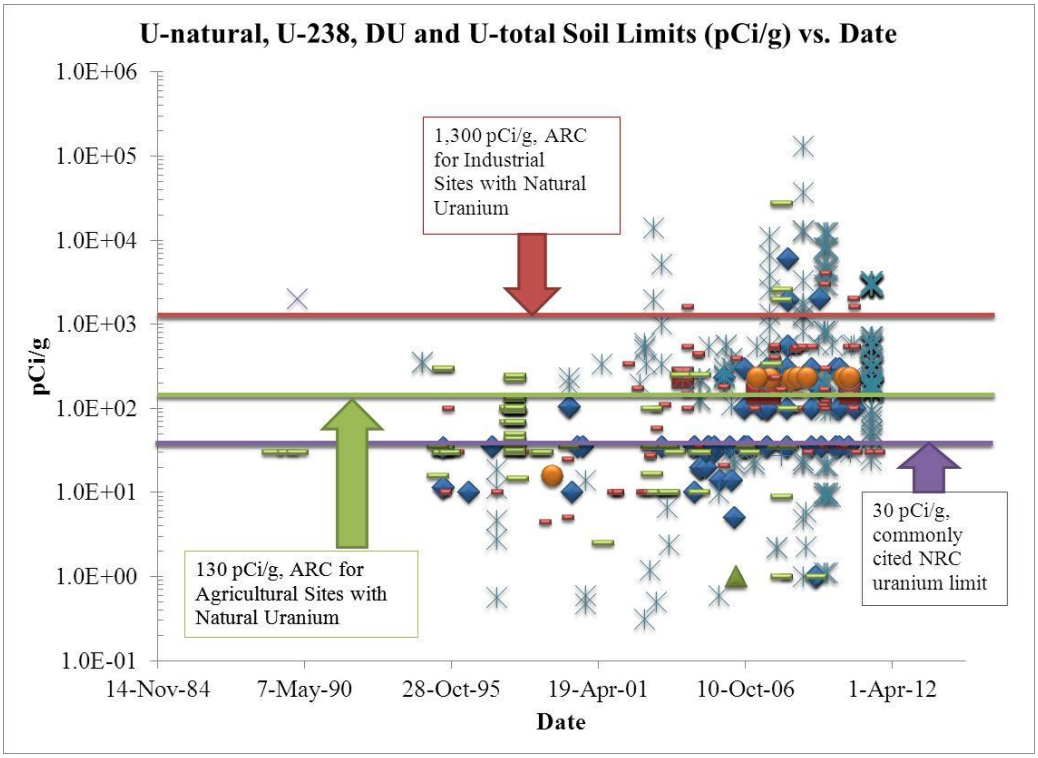

Figure 1, Non-enriched Uranium Limits vs. Date, Nationwide, USA

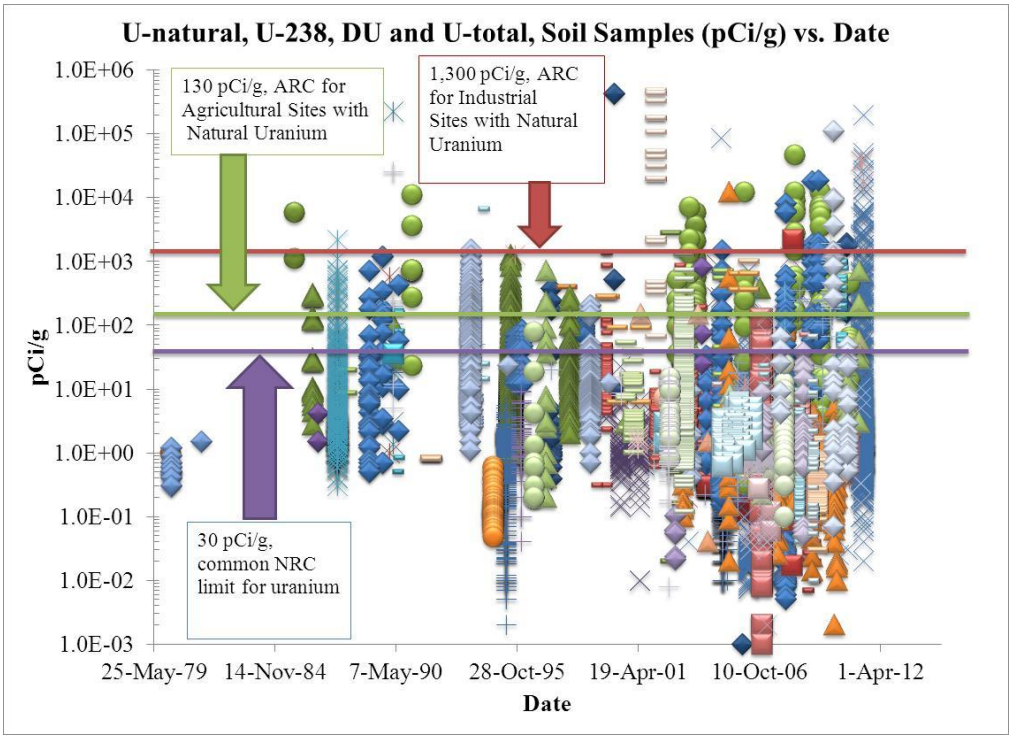

Figure 2, Non-enriched Uranium Soil Samples vs. Date, Nationwide, USA

The non-enriched uranium (Figure 2) concentration in soil can span nine orders of magnitude. Given the wide range possible for uranium concentration, variation in requirements becomes more reasonable. The requirements promulgated by the NRC appear to be adjusted to fit the measurement values, IAW ALARA principles regarding economic concerns. At sites with higher contamination, there were higher limits.

INTRODUCTION

Regulations regarding uranium soil contamination originate within the EPA. The EPA is responsible for calculating the maximum dose, concentration or environmental release limits. Generally, the EPA seeks to keep the risk of cancer or other deleterious effects to less than 1 event per million populations, and focuses on ñat riskò individuals. The EPA then issues limits, and the NRC (ñthe Commissionò) converts the limits to rules, regulations and limits for licensed facilities.

ñIn the case of sites at which ores are processed primarily for their source material content or which are used for the disposal of byproduct material as defined in section 11e.(2), a licensee may propose alternatives to specific requirements adopted and enforced by the Commission under this Act. Such alternative proposals may take into account local or regional conditions, including geology, topography, hydrology, and meteorology.

The Commission may treat such alternatives as satisfying Commission requirements if the Commission determines that such alternatives will achieve a level of stabilization and containment of the sites concerned, and a level of protection for public health, safety, and the environment from radiological and non-radiological hazards associated with such sites, which is equivalent to, to the extent practicable, or more stringent than the level which could be achieved by standards and requirements adopted and enforced by the Commission for the same purpose

and any final standards promulgated by the Administrator of the Environmental Protection Agency in accordance with section 275.94 of the Atomic Energy Act of 1954.ò

Typically, with radioactive materials, the risk is due to radiation dose; however, for uranium, the risk is chemical toxicity (Agency for Toxic Substances and Disease Registry, 2011). Although the NRC has extensive experience with radioactive materials, and assessing the risk from radiation, uranium is a radionuclide where chemical toxicity could be the controlling factor for regulatory action.

Upon review of the NRC records on uranium soil, contamination limits seem to depend upon the initial uranium contamination level, but not by date or site (Figure 3). The overall goal of any limit is to prevent deleterious effects to humans and the environment. There are two main pathways through which uranium soil contamination can impact human health:

1. Ingestion via drinking, food consumption, or soil consumption
2. Inhalation via dust or re-suspension of soils

A thorough analysis of each pathway is necessary in order to establish effective uranium soil contamination limits. An evaluation of each pathway may be site specific, but an overall limit could be more cost effective, and could provide the public with greater assurance that public

health has been considered. Furthermore, the concentration of uranium in soils at any given site may vary by many orders of magnitude, either through anthropomorphic intervention or due to primordial action and this too could be a key consideration in establishing limits for uranium contamination in soils such that deleterious effects on humans and the environment are avoided.

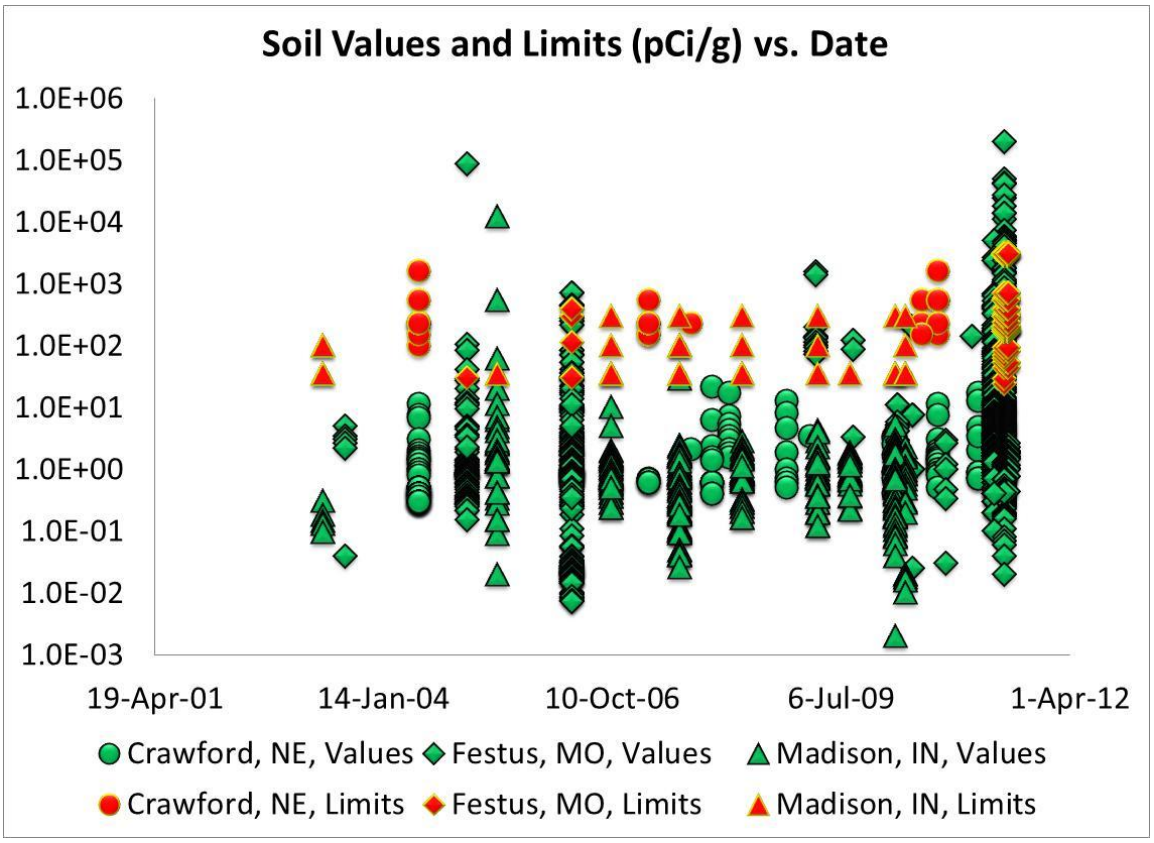

Figure 3, Values vs. Limits at Three Sites. Note log scale for ordinate.

The toxicity of uranium is impacted by the uranium valence state (Eidson, 1994), chemical form (Agency for Toxic Substances and Disease Registry, 2011), physical state (solid, liquid, and gas), solubility (Diamond, 1989), proximity to the public, and concentration. The concentration, solubility, and chemical state of uranium play the largest role in determining uptake and toxicity. The Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profile for

Uranium (May 2011) details the solubility-toxicity link in their report (Agency for Toxic Substances and Disease Registry, 2011):

ñSoluble uranium compounds (e.g., uranyl nitrate, uranyl fluoride, uranium hexafluoride, and uranium tetrachloride) are more toxic than insolubleò

Although statistically weak, an increased risk of mortality from lung cancer has been linked to decreasing solubility of reprocessed uranium compounds, in particular uranium oxide (Canu et al, 2010). Modern uranium millers deliberately avoid producing insoluble uranium compounds by drying yellowcake at temperatures under 400 ^{o}C (low-fired yellowcake) rather than forming insoluble compounds by drying at temperatures over 400 ^{o}C (high-fired yellowcake). (US NRC, Reg Guide 1.86, 1988) (Edison and Damon, 1984).

The chemical composition of uranium (such as U_3O_8, UO_2, UO_3 or UF_6), is almost entirely responsible for the uraniumôs behavior in the environment and human body, and that behavior in turn is based partially on solubility. If a compound is not soluble in water, it is somewhat difficult to incorporate biologically. The oxides of uranium (U_3O_8, UO_2 or UO_3) are not soluble in water but the fluorides and nitrates of uranium (UCl_4, UF_6, $UO_2(NO_3)_2 \bullet 6H_2O$) are somewhat water soluble. Enriched uranium poses different risks, depending on the level of enrichment, and is beyond the scope of this paper. NRC data on enriched uranium in the form of U-233/234, U-235 and U-236 are featured in Appendixes B, C, and D.

This paper provides an overview of NRC uranium soil contamination limits used over the past 30+ years, and seeks to recommend soil contamination limits for uranium that protect human health, the environment and allow for productive use of uranium in accordance with the ICRP principals of optimization.

Uranium Overview

Table 2, Primary uranium ores, from ATSDR

Ore	Chemical composition	Description
Uraninite	$UO_2 + UO_3$	A steel, velvet, brownish-black major ore of uranium and radium
Pitchblende	$UO_2 + UO_3$	Essentially the same as uraninite
Brannerite	$U(TiFe)_2O_2$	A brownish-black-olive-green ore, primary mineral in granite, associated with uraninite
Coffinite	$U(SiO4)_{1-x}\ (OH)_{4x}$	A black or pale to dark brown mineral in sandstone and silica, associate with uraninite
Davidite	$(CeLa)U(TiFe^{3+})_{20}(O,OH)_{38}$	A black-brownish mineral in granite
Thucholite	Uranite, sulfide and hydrocarbon mix	A black slush
Carnotite	K_2O Å2U_2O_3 ÅV_2O_5 Å3H_2O	Bright, lemon or greenish-yellow mineral in sandstone associated with tyuyamunite and U-V oxides

Uranium is the heaviest naturally occurring metal on Earth, and one of the primordial radionuclides (Ahier and Tracy, 1995). At 1000 mg/kg (0.1%, 336 pCi/g, 12.4 Bq/g) a mineral

sample can be considered uranium ore. Natural uranium (U-nat) is 99.27% U-238, 0.72% U-235 and 0.01% U-234, by weight on the average (Brugge et al, 2005). The average uranium concentration in soil is approximately 3 ppm (2 pCi/g, 2.8 mg/kg, 0.07 Bq/g) (Brugge et al, 2005, Bleise et al, 2003). Uranium ore can be in many states (Tables 2 and 3) but generally is processed into yellowcake (U_3O_8) at a mill or a processing plant for an in-situ uranium facility.

Table 3, Secondary uranium ores, from ATSDR

Ore	Chemical composition	Description
Autunite	Ca $(UO_2)_2$ $(PO_4)_2$ Å10 H_2O	Yellow-to-greenish mineral produced under oxidizing conditions and associated with tormernite
Torbernite	Cu $(UO_2)_2$ $(PO_4)_2$ Å10 H_2O	An emerald-, grassy-, to apple-green mineral formed in an oxidized zone and associated with uraninite and autunite
Tyuyamunite	Ca $(UO_2)_2$ $(VO_4)_2$ Å5-8 H_2O (uranium calcium vanadate)	A canary-, lemon-, to greenish-yellow mineral associated with carnotite

Most natural uranium ore is a form of uranium oxide with UO_2 and UO_3 the most common (Tables 2 and 3). Natural uranium is either mined from an open pit, underground mine, or ñin situò mining and processed into yellowcake which is ~85% U_3O_8 (Anastasi and Williams, 1984).

As uranium ore is processed into yellowcake, the radioactive daughter products are stripped away and are a separate concern. The yellowcake (U_3O_8) is transported to another facility and then chemically converted into uranium hexafluoride (UF_6). Further processing then enriches the UF_6 to increase the U-235 content and converts the UF_6 into uranium dioxide (UO_2) for use in nuclear reactors. Depleted uranium (DU) is UF_6 or UO_2 that is depleted in U-235 below the natural level of ~0.7%. (Figure 4)

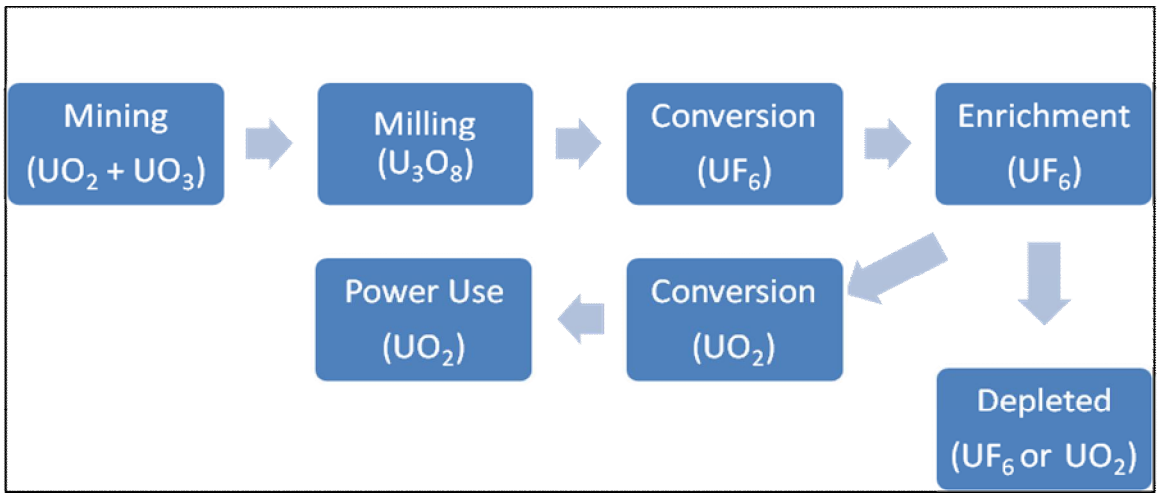

Figure 4, The ñFront Endò of the Uranium Fuel Cycle

Depleted uranium (DU) is a UF_6 or UO_2 byproduct of the uranium fuel-enrichment process, enriched in U-238 and lower in U-235 than U-nat. DU used in military munitions has been converted to UO_2 and is not water soluble. DU is used in military munitions due to its high density, self-sharpening and pyrophoric characteristics that make it very effective at penetrating armored targets. DU is also used in aviation as counterbalance weights as well as shielding in radiation therapy rooms, industrial radiography and other locations (AFRRI, 2010). The isotopic ratio in DU (<0.7% U-235) causes it to behave almost identically to natural uranium of the same chemical form with regard to biological effects.

Uranium Chemistry

As seen in Tables 4 and 5, the chemical compounds of uranium have vastly different chemical properties, and while solubility is a factor, biochemical and chemical reactions are far more than just determining what dissolves in water. The biochemistry and chemistry of uranium is what drives the toxicity or lack thereof for the various uranium chemical compounds.

Table 4, Oxygen compounds of uranium (The Merck Index, 1996)

Chemical Formula	UO_2	UO_3	UO_4	$UC_4H_6O_6$	U_3O_8
Name	Uranium dioxide	Uranium trioxide	Uranium peroxide	Uranyl acetate	Triuranium octoxide
Appearance	Brown to black powder or cubic crystals	Red or brownish powder	Pale yellow crystals	Yellow crystals	Olive green to black
Solubility and reactivity		Soluble in acids		Water	Nitric acid and sulfuric acid
Molecular Weight (g/mol)	270.03			388.12	842.1
Chemical reactions of interest			Decomposes slowly in the 90 to 195 C range. Hydroscopic.	Used as an activator in the bacterial oxidation process	Very inert

Table 5, Nitrogen compounds of uranium (The Merck Index, 1996)

Chemical Formula	$(NH_4)_2U_2O_7$	$UO_2CO_3 \cdot 2(NH_4)_2CO_3$	$UO_2(NH_4)_3F_5$	$UO_2(NO_3)_2$ $6H_2O$
Name	Ammonium diuranate	Ammonium Uranium Carbonate	Ammonium uranium fluoride	Uranyl nitrate
Appearance	Reddish-yellow, amorphous powder	Yellow crystals	Greenish-yellow, monoclinic crystal powder	Yellow rhombic crystals
Solubility and reactivity	Practically insoluble in water and alkalies; soluble in acids or ammonium carbonate solution	Freely soluble in water.	Freely soluble in water, practically insoluble in alcohol	Water and alcohol.
Molecular Weight (g/mol)	624.13	522.21		502.13
Chemical reactions of interest	Used for painting black on porcelain	Decomposed on exposure to air and used in uranium yellow glazes	Fluoresces under x-rays	Detonates upon contact with sunlight.

An example of the importance of the chemical form of uranium in its behavior is UF_6. Uranium hexafluoride reacts with water (even water vapor) producing uranium dioxide difluoride (UO_2F_2) and hydrofluoric gas. While the radiological and chemical toxicity of uranium might be of only mild concern, hydrofluoric gas is toxic and a concern for inhalation, skin burns and can be part of large concentrations of acidic aerosols (Pacific Northwest Laboratory, PNL-10065, 1994 and US NRC, NUREG-1391, 1991). Due to uranium hexafluorideôs chemical toxicity, volatility, and

purely industrial use, uranium hexafluoride is not considered in the Alternate Release Criteria (ARC) limits.

Regulatory Oversight of Uranium

Although the NRC primarily regulates uranium, multiple other agencies have input or directly regulate uranium. The agencies or regulations that either currently or formerly influenced uranium limits are:

The Code of Federal Regulations (CFR)

The Energy Reorganization Act of 1974

Energy Research and Development Administration (ERDA)

Department of Energy (DOE)

Occupational Health and Safety Administration (OSHA)

Environmental Protection Agency (EPA)

Science Advisory Board (SAB) EPAôs Radiation Protection Division

Nuclear Regulatory Committee (NRC)

Center for Disease Control (CDC)

Department of the Interior (DOI)

Office of Surface Mining (OSM)

Department of Labor (DOL)

Department of Transportation (DOT)

Mine Safety and Health Administration (MSHA)

Department of Defense (DoD)

Interagency Steering Committee on Radiation Standards Subcommittee (ISCORS)

In addition, ñagreement statesò also have control over the uranium use in their state, unless the state asked the NRC to take over that role.

There are also national and international advisory agencies that can give guidance that often becomes transcribed into law.

International Atomic Energy Agency (IAEA)

International Commission on Radiological Protection (ICRP)

American Conference of Industrial Hygienists (ACGIH)

National Mining Association (NMA)

National Academy of Sciences (NAS)

Conference of Radiation Control Protection Directors (CRCPD)

Uranium Workers

Based upon the NRC ADAMS documents, most USA mining and milling was and is in the Mountain West within sandstone containing coffinite and uraninite (Ludwig and Grauch, 1980). Most uranium processing after milling is performed in the Southern and Eastern USA. For a detailed list of locations, uses, dates, and ADAMS document numbers, please see Appendix A.

DATA, MATERIALS AND METHODS

Overview of NRC Uranium Limits and Values

The NRC regulations and website do not identify a specific limit for the concentration of uranium in soils nor was a scientific basis for the current uranium contamination limit located. The NRCôs ADAMS documents and citations were researched to determine the historical and current uranium soil contamination limits and their origin. NRC guidance on uranium soil concentration appears to focus exclusively on the element uranium rather than the chemical form or the anticipated chemical form in the environment. Minimal reference to uranium solubility is made in any of the documents on soil contamination.

The most common limits cited in the ADAMS documents are:

1. Derived Concentration Guideline Levels (DCGLs)
    a. DCGL(w)
    b. DCGL(EMC)
2. Action Levels
3. ALARA Limits
4. Clean Up Levels
    a. Clean Up (w)
    b. Clean Up (EMC)

5. General Limits
6. NRC Guidance
7. Levels generated from EPA drinking water standards

These limits were most commonly cited for soil and sediment. DCGLs relate concentrations of a specific radionuclide to a specific risk. For example, the DCGL can be based on a resident gardener (who eats her own vegetables) or the owner of an orchard or other member of the public. A (w) placed behind a DCGLs and Clean Up Levels indicates residual radioactivity evenly distributed over a large areas.

The (EMC) placed next to DCGLs and Clean Up Levels stands for ñElevated Measurement Exposureò and is essentially used for ñhot spotsò when small areas of elevated radioactivity exist on site.

The (w) and (EMC) limits for DCGLs and Clean Up Levels were utilized mostly at the following more contaminated sites:

1. Festus, MO
2. Newfield, NJ
3. West Valley, NY
4. Hematite, MO

Most of the values cited are for either soil or sediment, with the bulk of the values falling into the soil category. Other values are provided for vegetation, water, minimum detectable activity (MDA), background, meat and bones (herbivore and carnivore), sludge, slime, and slag.

In addition, the consolidated NMSS decommissioning guidance set forth by the NRC suggests a screening level of 14 pCi of U-238 per gram of soil (US NRC, NUREG-1757, 2003).

Natural Uranium

Natural uranium is uranium that has not been enriched or depleted. One of the earliest uranium soil contamination limits issued by the NRC was on 24MAY95. The US Energy Corp at the Green Mountain Ion Exchange in Riverton, Wyoming was directed that their limit would be 172 pCi/g (6.35 Bq/g). This earliest standard was further modified on 08JUN95 to 10, 24, or 33 pCi/g (0.37, 0.89, or 1.22 Bq/g), depending upon which part of ML081540395 is referenced. The standard varied little in the late 20th century but in the early part of the 21st century the natural uranium contamination standard varied considerably (Figure 5).

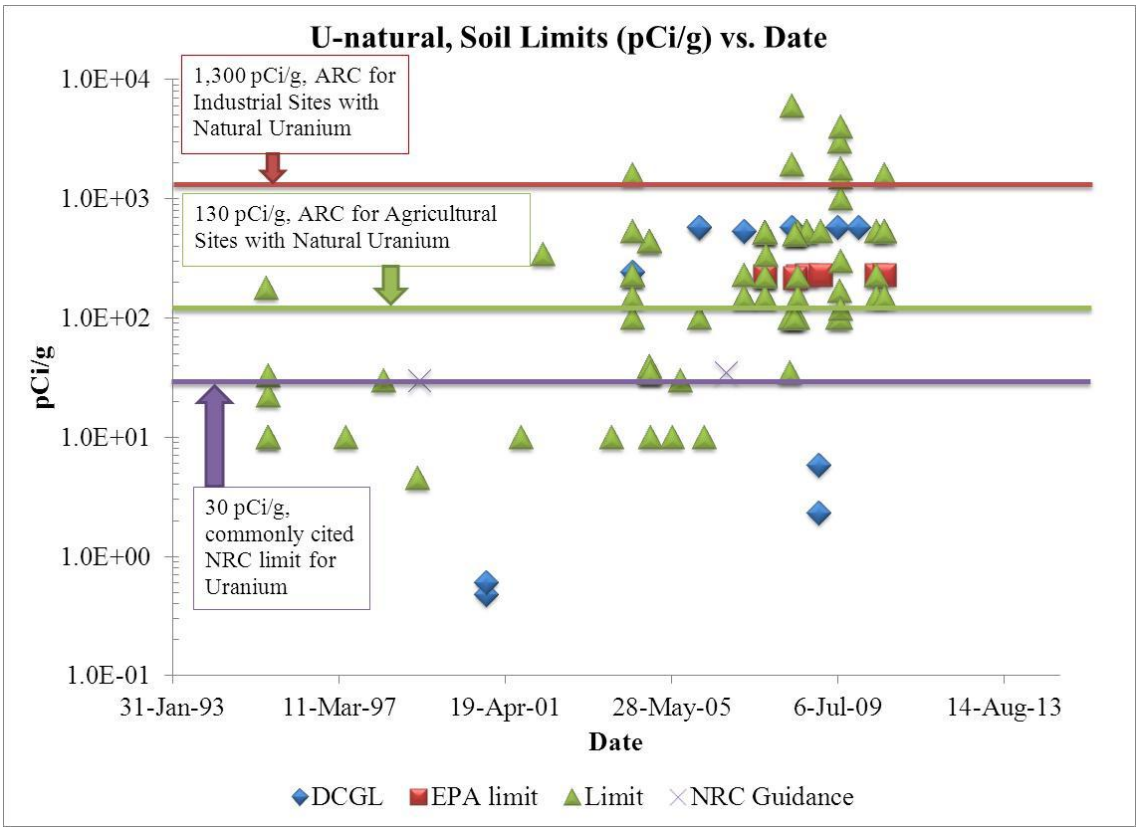

Figure 5, Natural Uranium Limits vs. Date, Nationwide, USA

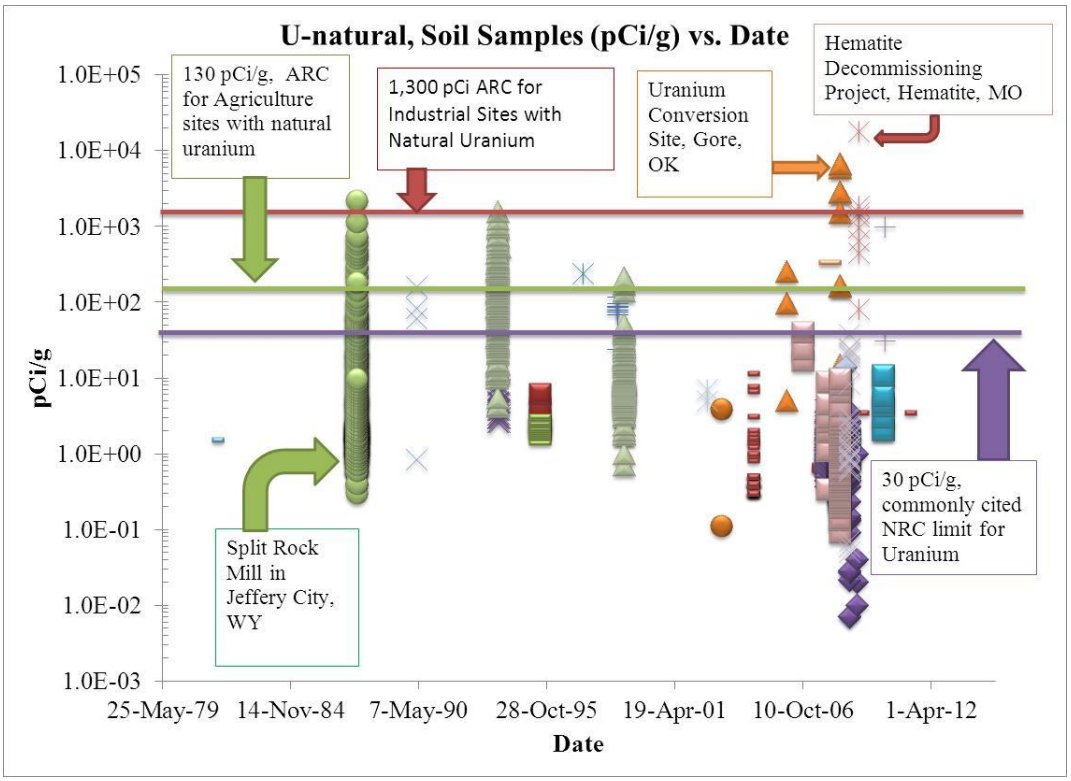

Figure 6, Natural Uranium Soil Samples vs. Date, Nationwide, USA

Only three sites had published soil sample values that exceeded the alternate release criteria for (ARC) proposed for natural uranium (UO_2 and UO_3) (Figure 6) and they were uranium mills, enrichment sites or conversion sites. While the locations vary from as far west as Monument Valley, Arizona to as far east as Aberdeen Proving Grounds, Maryland (Figure 7), it appears that any given site can be as low as 10^{-2} pCi/g (3.7×10^{-4} Bq/g) to as high as 10^{4} pCi/g (3.7×10^{2} Bq/g) (Figure 6).

Figure 7, Legend for Figure 6.

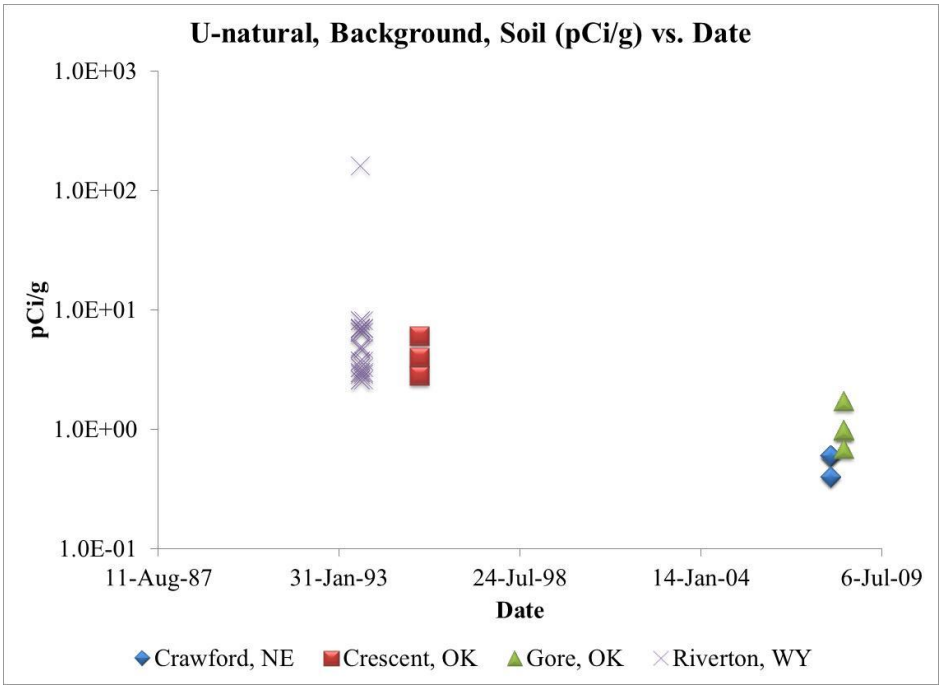

Figure 8, U-nat, Background Samples vs. Date, NE, OK and WY

Background levels (Figure 8) were rarely cited in all the ADAMS documents reviewed, but in general background natural uranium values varied from 0.4 to 162 pCi/g (1.5×10^{-2} to 6.0 Bq/g).

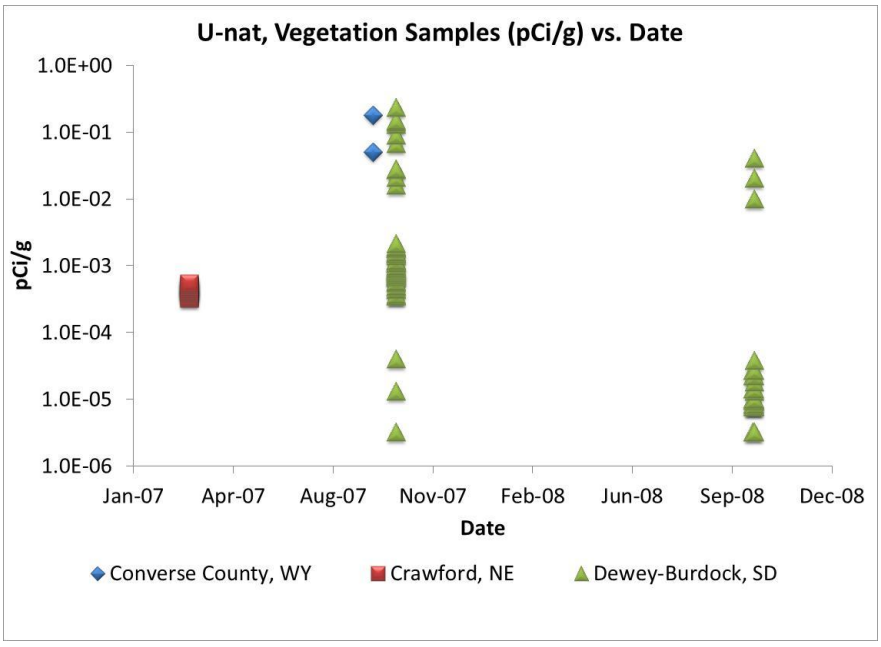

Figure 9, U-nat, Vegetation Values vs. Date, WY, NE and SD

As seen in Figure 9, the vegetation can vary by almost six orders of magnitude at any given site for natural uranium content, but do not exceed 1 pCi/g (3.7×10^{-2} Bq/g).

Non-enriched Uranium

Natural uranium, U-238, depleted uranium (DU) and total uranium all fall under ñnon-enrichedò and were therefore grouped as one data set. The background levels of non-enriched uranium vary greatly by location, date and even sample at any given location (Figure 10).

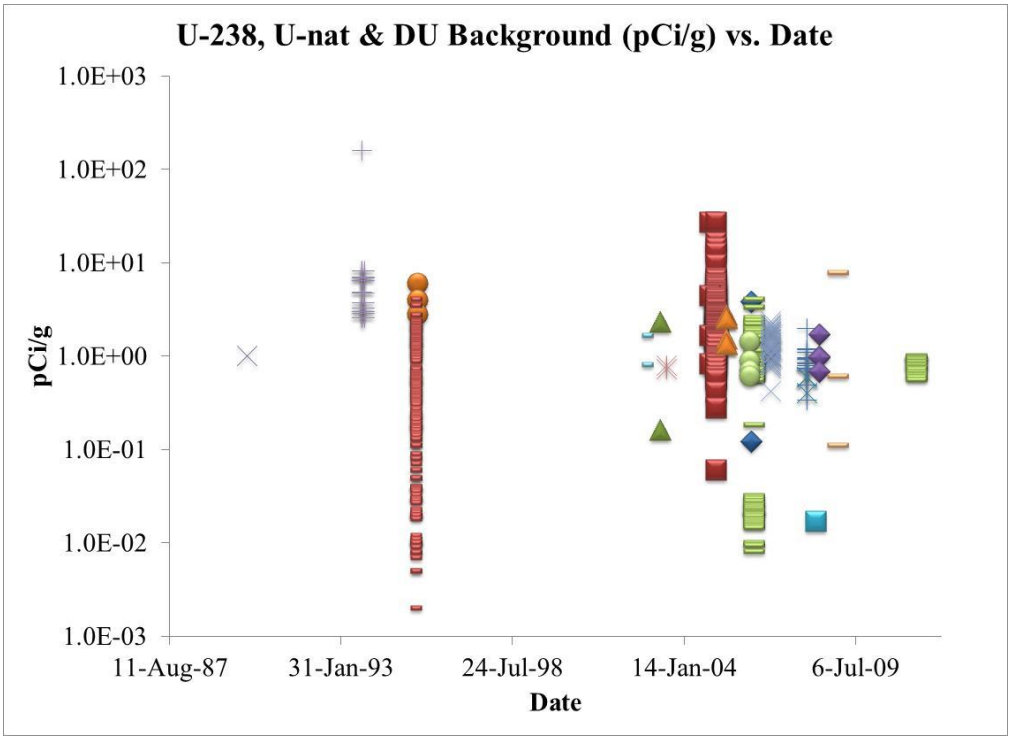

Figure 10, Non-enriched Background Values vs. Date

These background values were taken at various locations across the USA (Figure 11).

Figure 11, Legend for Figure 10

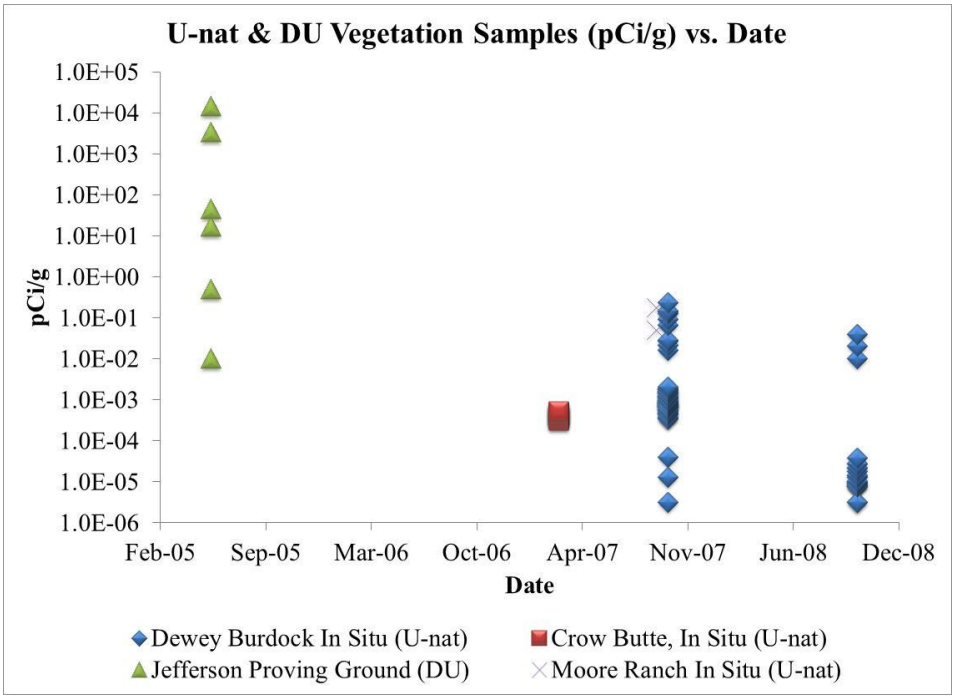

Figure 12, Natural Uranium and DU in Vegetation vs. Date

For natural uranium, vegetation does not exceed 1 pCi/g but on the DU firing line berm at Jefferson Proving Ground, Indiana, the concentrations in DU in vegetation can exceed 1 pCi/g (Figure 12).

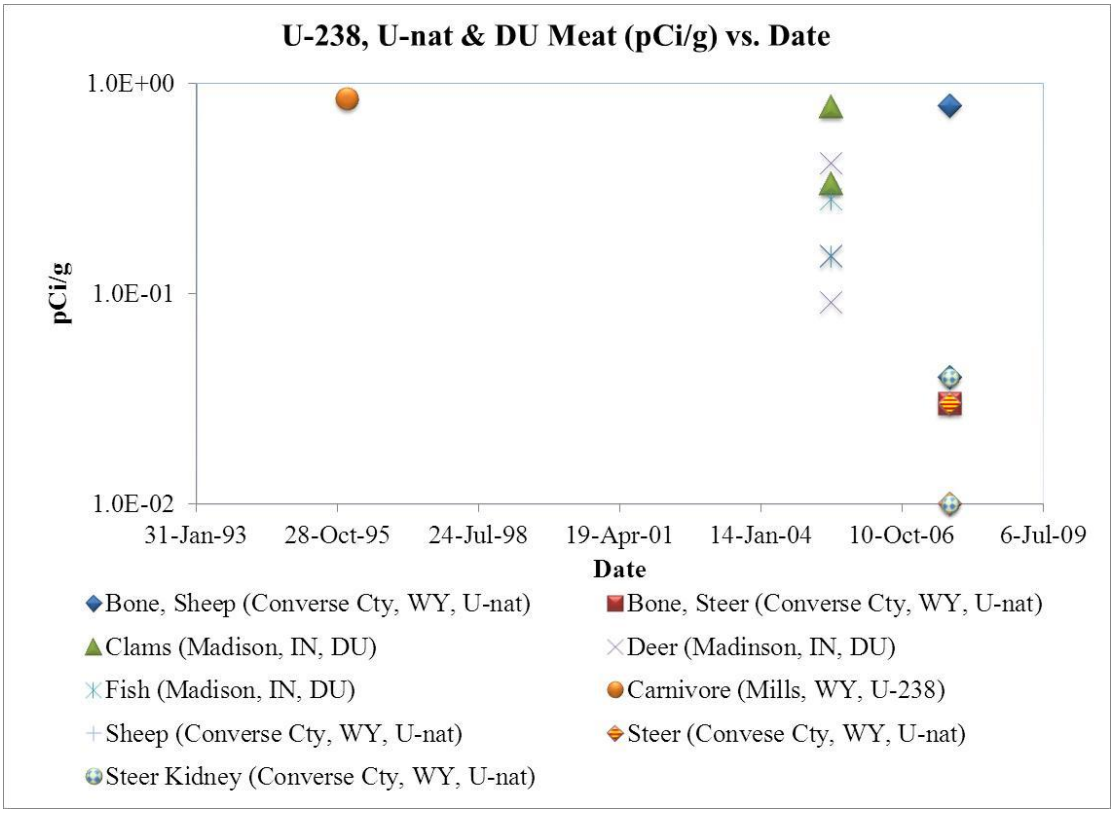

Figure 13, U-238, National Uranium and DU in Meat and Bone vs. Date

Even near the firing berm at Jefferson Proving Ground in Madison, Indiana, the concentration of uranium in meat and bones of animals never exceeded 1 pCi/g (Figure 13). The data from harvested animals is very scarce and limited data is available.

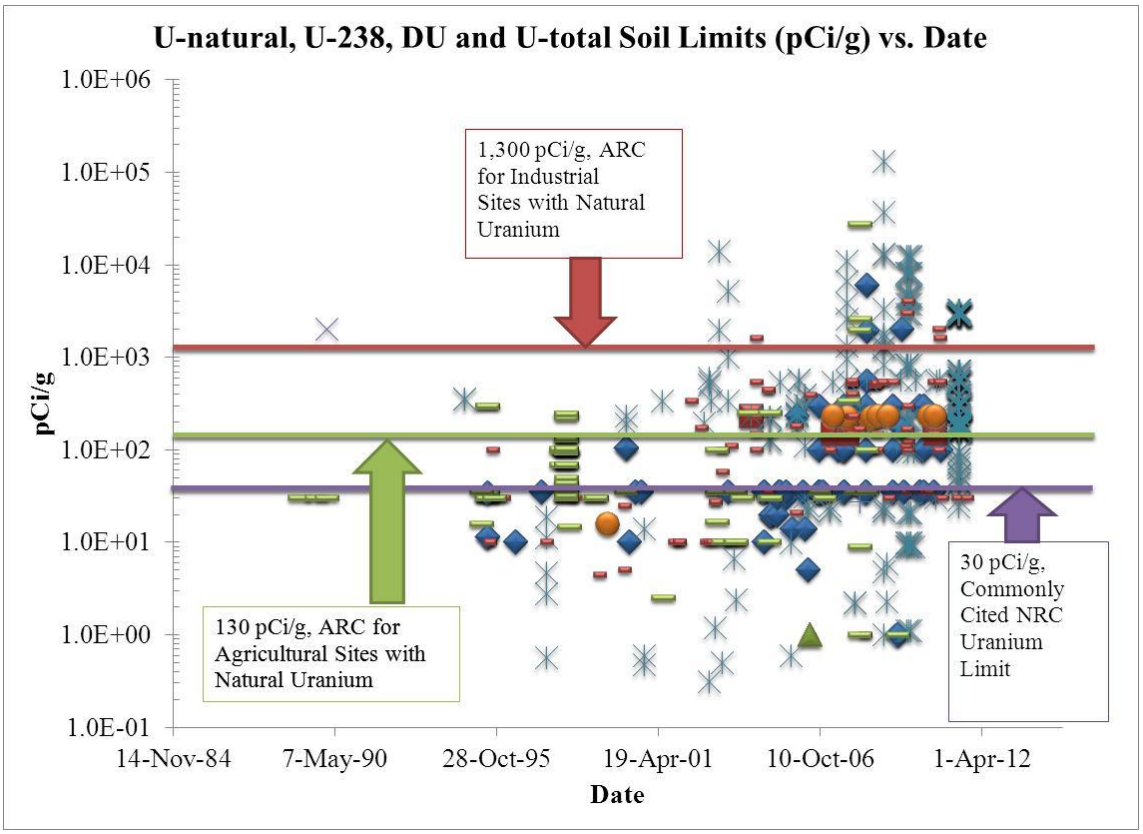

Figure 14, Non-enriched Uranium Soil Limits vs. Date, Nationwide, USA

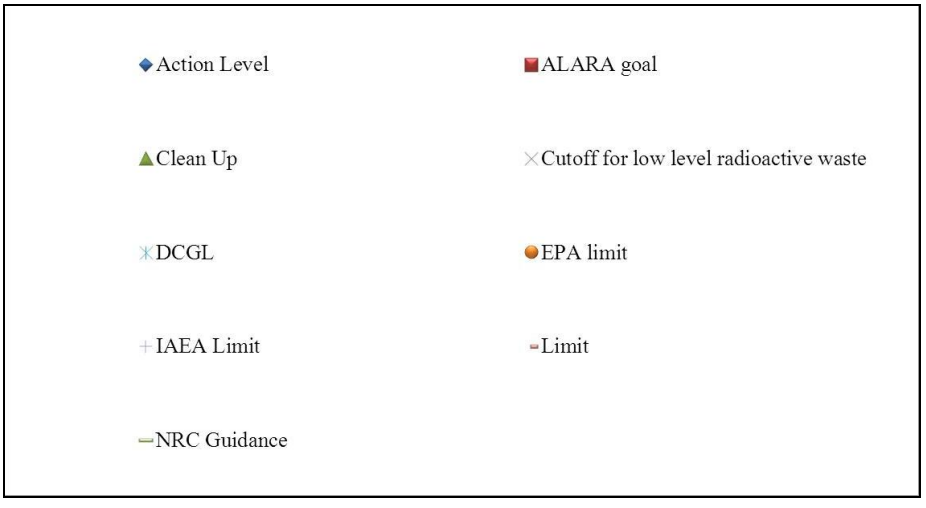

Figure 15, Legend for Figure 14

The limits can vary by almost six orders of magnitude (Figure 14), as well as by time and type of limit (Figure 15). These various limits from various sites on various dates make an overall comparison very difficult but overall the number of limits increases over time. There are more proposed limits in the 21st century than the 20th century.

The limit cited most frequently by the EPA and the NRC was 30 pCi/g (1.1 Bq/g), but locally imposed action levels, clean-up limits, Derived Concentration Guideline Levels (DCGLs), IAEA limits, ALARA goals and associated limits can vary by almost six orders of magnitude (Figure 14).

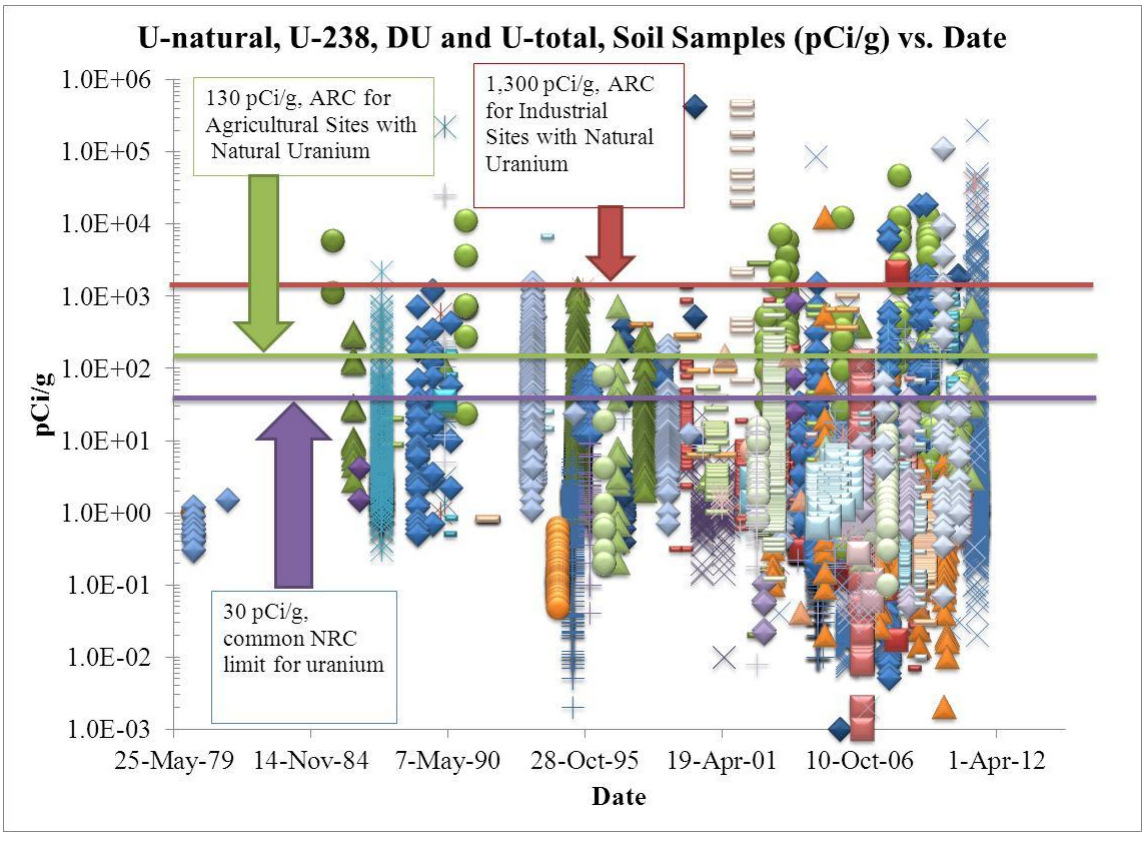

Figure 16, Non-enriched Uranium Soil Samples vs. Date

The non-enriched uranium soil values can vary from 10^{-3} pCi/g (3.7×10^{-5} Bq/g) to almost 10^{6} pCi/g (3.7×10^{4} Bq/g) depending upon the site, date and number of samples taken (Figure 16).

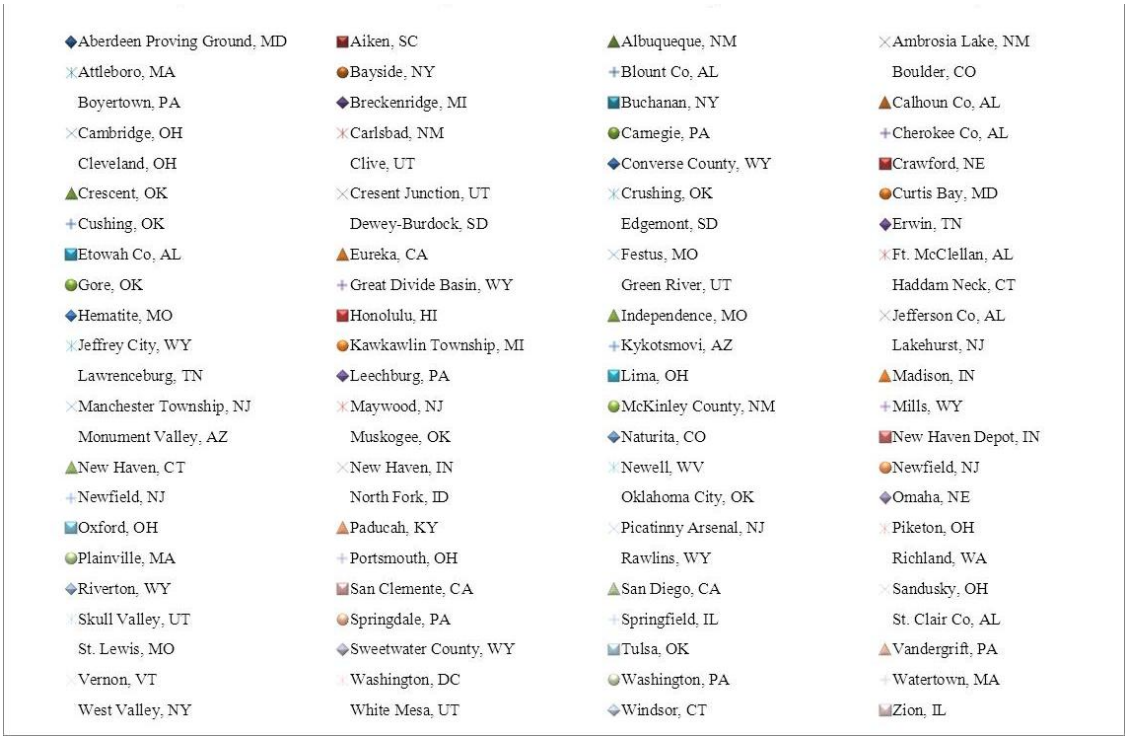

Figure 17, Legend for Figure 16

As seen in Figure 17, non-enriched uranium has been sampled in many locations across the USA. The sites that exceed the ARC natural uranium limit of 1,300 pCi/g (48 Bq/g) are places where refined uranium has been used (Table 6). These include uranium mills, enrichment sites, uranium glaze factories, US Army DU firing ranges, US Navy power plant support operations, former Manhattan Project sites as well as other sites that use refined uranium (Table 6).

Table 6, Sites that exceeded ARC suggested limits

Company	Site	Geographic Location
US Army	Depleted Uranium Study Area (DUSA) of the Transonic Range	Aberdeen Proving Grounds, MD
Texas Instruments, Inc.	Fabrication of enriched uranium foils (starting in 1952)	Attleboro, MA
Cabot Supermetals, Inc	Cabot Supermetals Facility	Boyertown, PA
Superior Steel & Metals Corporation	Uranium metal strip and plate fabrication site	Carnegie, PA
Westinghouse Electric Corporation	Hematite Decommissioning Project	Festus, MO
General Atomics	Sequoyah Fuels Uranium Conversion Facility	Gore, OK
Westinghouse Electric Corporation	Hematite Nuclear Fuel Manufacturing Facility	Hematite, MO
US Army	Pohakuloa Training Area and Schofield Barracks	Honolulu, HI
Western Nuclear, Inc.	Split Rock Mill	Jeffrey City, WY
Heritage Minerals	Heritage Minerals	Lakehurt, NJ
US Army	Jefferson Proving Ground	Madison, IN
United States Enrichment Corporation	Portsmouth Facility	Piketon, OH
Kennecott Uranium Company	Sweetwater Uranium Facility	Rawlins, WY
US Energy Corp	Green Mountain Ion Exchange	Riverton, WY
Andrews Engineering Inc.	Honeywell Ponds	Springfield, IL
Mallinckrodt Inc.	Columbium-Tantalum (C-T) Plant	St. Lewis, MO
General Services Administration	Former Manhattan District Site (AEC, US Army, etc…)	Watertown, MA
International Uranium (USA) Corporation	White Mesa Mill	White Mesa, UT
ABB Mactec	CE Winsor Site	Windsor, CT

Radiological Toxicity of Uranium

The scientific consensus for over a decade has been that the chemical toxicity of uranium (inhaled or ingested) is greater than the radiotoxicity (Pacific Northwest Laboratories, PNL-10065, 1994 and Agency for Toxic Substances and Disease Registry, 2011).

The calculation of radiation dose due to uranium assumes that there are no daughters or decay products present after the milling process (Bleise et al, 2003). This assumption is reasonable,

since after uranium ore has been extracted and milled, it is essentially pure uranium with no other elements present.

Radon

Radon-222 (Rn-222) is the daughter of radium-226 (Ra-226), a daughter product of uranium-238 (U-238) (U.S. EPA, 1986 and 2008) and has been found in uranium mines in Germany as far back as the 1940s (Lorenz, 1944). Radon comprises almost half of the natural radiation dose the public receives annually. When natural uranium is milled and the daughter products are stripped away, thorium (Th-234) and protactinium (Pa-234) reach secular equilibrium with the U-238 parent in about one year, and are the only major contributors to radiation dose in processed uranium (Bleise et al, 2003).

Possibly due to the radiological toxicity of Rn-222, the Department of Energy Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities (DOE-STD-1136-2009) requires radiation monitoring of thorium and radium (Ra-226, Ra-228, Th-230, and Th-232) rather than uranium because both thorium and radium have a higher specific activity. The DOE defers specific guidelines for uranium in soil to be derived based upon the basic dose limit by means of an environmental pathway analysis using specific property data where available (Department of Energy, 2009).

Uranium Radiation Dose

The contact dose rates with a slab of natural uranium are 0.1 mSv of γ and 2.8 mSv of β per hour (Brodsky and Kathren, 1989). One year of physical contact with a slab of natural uranium could produce of dose of 25.4 Sv, which exceeds the NRC annual limit for skin (0.5 Sv). Only the beta and gamma components of uranium contribute to external dose and the organ affected is the skin at 2 mSv/hr (Bleise et al, 2003). Thus, direct physical contact with large quantities of pure uranium can deliver a significant dose, but this situation is not practical and cannot be used for a comparison for soil contamination. The radiological dose due to contact with uranium in contaminated soil is significantly below 50 mSv (5 rem) per year for radiation workers (ICRP 68) or 1 mSv (0.1 rem) for members of the public (ICRP 72).

Based upon radiation dose conversion factors (Johnson and Birky, 2012), the dose to a human being standing on natural uranium in the soil can be calculated (Figure 18).

$$\left(\frac{1\,\text{pCi}}{\text{g}}\right)_{\substack{\text{Uranium}\\ \text{in soil}}}\left(\frac{1.3\,\text{g}}{\text{cm}^3}\right)_{\substack{\text{Soil}\\ \text{Density}}}\left(\frac{10^6\,\text{cm}^3}{\text{m}^3}\right)\left(\frac{\text{Bq}}{27\,\text{pCi}}\right)\left(\frac{4.26\times10^{-22}\,\text{Sv}\bullet\text{m}^3}{\text{Bq}\bullet\text{sec}}\right)_{\substack{\text{Infinte}\\ \text{Surface}\\ \text{U}-238}}\left(\frac{31{,}557{,}600\,\text{sec}}{\text{year}}\right)\left(\frac{10^9\,\text{nSv}}{\text{Sv}}\right)=0.65\frac{\text{nSv}}{\text{year}}$$

$$\left(\frac{10^6\,\text{pCi}}{\text{g}}\right)_{\substack{\text{Uranium}\\ \text{in soil}}}\left(\frac{1.3\,\text{g}}{\text{cm}^3}\right)_{\substack{\text{Soil}\\ \text{Density}}}\left(\frac{10^6\,\text{cm}^3}{\text{m}^3}\right)\left(\frac{\text{Bq}}{27\,\text{pCi}}\right)\left(\frac{4.26\times10^{-22}\,\text{Sv}\bullet\text{m}^3}{\text{Bq}\bullet\text{sec}}\right)_{\substack{\text{Infinte}\\ \text{Surface}\\ \text{U}-238}}\left(\frac{31{,}557{,}600\,\text{sec}}{\text{year}}\right)\left(\frac{10^3\,\text{mSv}}{\text{Sv}}\right)=0.65\frac{\text{mSv}}{\text{year}}$$

Figure 18, Dose per Year from Natural Uranium

For most contaminated soils, typical uranium concentrations range from 1 pCi/g (3.7×10^{-2} Bq/g) to higher concentrations at uranium mines, mills and Army DU firing ranges of up to 10^6

pCi/g (3.7×10^4 Bq/g). The doses from standing and living on that level of uranium concentration are given above. The worst case dose estimate is 0.65 mSv per year, which well below the ICRP 72 annual limit for members of the public (1 mSv).

Chemical Toxicity of Uranium

The uranium compounds of most concern for chemical toxicity are triuranium octoxide (U_3O_8), uranium hexafluoride (UF_6), uranium dioxide (UO_2) and uranium trioxide (UO_3). The NRC concluded that an intake of about 10 mg of soluble uranium is almost analogous, in terms of early effects, to an acute whole body dose of 25 rems (0.25 Sv) since it is just below the threshold for significant deterministic effects (NUREG-1391, 1999).

However, the primary hazard from UF_6 is the hydrogen fluoride intake resulting from the UF_6 interaction with water in the air (US NRC, NUREG-1391, 1991). For comparison, the Occupational Safety and Health Administrationõs (OSHA) Permitted Exposure Limit (PEL) for insoluble uranium in the workplace is 0.25 mg/m^3 (8ï hour TWA) and 0.05 mg/m^3 for soluble uranium (Table 7), resulting in an eight hour intake of 2.4 mg per day for insoluble and 0.48 mg per day for soluble uranium.

Table 7, Regulatory Limits for Uranium (http://www.cdc.gov/niosh/idlh/uranium.html)

	mg/m3		
	NIOSH REL	NIOSH STEL	OSHA PEL
Uranium (insoluble)	0.2	0.6	0.25
Uranium (soluble)	0.2	0.6	0.05

The American Conference of Governmental Industrial Hygienists (ACGIH) has a Threshold Limit Value (TLV) for insoluble uranium of 0.2 mg/m^3 (Time Weighted Average) (1.92 mg/d) TWA; 0.6 mg/m^3 STEL (5.76 mg/d) and lists uranium as a Confirmed Human Carcinogen (Table 8). Acceptable surface area contamination levels (US NRC, Reg Guide 1.86) are based upon the estimated resuspention factor (US NRC, NUREG-1400) to convert an uranium contamination hazard on a surface to an aerosol uranium hazard in the air.

Table 8, Insoluble Uranium Limits in Air

ACGIH TLV				ACGIH STEL			
mg/m^3	pCi/g	Bq/g	mg/d	mg/m^3	pCi/g	Bq/g	mg/d
0.2	4.6×10^{-13}	1.7×10^{-14}	1.92	0.6	1.4×10^{-13}	5.2×10^{-15}	5.76

Biological Effects of Uranium

ATSDR reports that the biological half-life of uranium (soluble or insoluble is not mentioned) is 11 days for the bone and 2 to 6 days for the kidneys (ATSDR, 2011). The LD_{50} for various uranium compounds is not well established, in part due to the high concentrations of uranium required for toxic action. With oral intake of uranium nitrate for diabetes patients the LD_{50} was

estimated to be 5 grams of uranium nitrate. There has never been a death attributable to uranium poisoning in humans, but in animal studies (rats and guinea pigs) large acute intakes of grams of various uranium compounds have been shown to produce death from chemical toxicity. Human beings seem to be hardier than the experimental animals in regards to both acute and chronic toxic effects of uranium (Kathren and Burklin, 2008).

Theoretically the LD_{50} could be as high as 5 g for a 70 kg ICRP Reference Man (1.68×10^6 pCi {6.2×10^4 Bq}per 70 kg reference man, 24 pCi {0.9 Bq} per gram of human flesh) for acute oral ingestion soluble and insoluble uranium. No death due to ingestion or inhalation of uranium has been recorded in human studies.

Soluble vs. Insoluble

NRC guidance on uranium is based on the chemical form defined only as soluble or insoluble, with no further specificity. Studies of inhaled particles and specifically inhaled uranium have shown that the chemical form dictates the biological impact of the uranium compound upon the human body (Stuart, 1984 and Edison, 1994). The chemical properties of uranium compounds vary greatly. The Annual Limit on Intake (ALI) does vary by isotope of uranium, but does not specifically enumerate that natural uranium and U-238 is a chemical hazard.

Physiology

Uranium elimination patterns have been addressed be various ICRP models (ICRP 30 and ICRP Lung Model). Pharmacokinetic models of uranium metabolism for bioassay and dosimetry continue to be proposed (Lawrence, 1984),(Wrenn, et al, 1994). Of the uranium that reaches the blood, 67% is excreted in the urine within the first 24 hours, and 85% of the uranium deposited in the bone leaves the body within 1.5 years. The lowest observed adverse effect level (LOAEL) in animal studies is 50 $\mu g/m^3$ for inhalation and 60 μg/kg body weight per day for ingestion (Brugge et al, 2005). For a 70 kg ICRP Reference Man this would imply that there is 100 to 125 μg of uranium with ~80% of the uranium not excreted ending up in the bones, and a daily intake of approximately 1 μg uranium (Hamilton, 1972).

Both the chemical form of uranium and the route of entry have a great impact on how uranium is handled in the body physiologically. For example uranyl acetate was shown to be highly toxic when given subcutaneously but only moderately toxic when given orally (Domingo, et al, 1987). Rat studies showed that only 0.4% of uranium nitrate from 24 hour immersion in a uranium nitrate solution is absorbed through intact skin (Petitot, et al, 2007).

Inhalation and Aerosols

Inhaled uranium will be either coughed up with the sputum (95%) or swallowed (5%) and then systemically absorbed and excreted in urine (5%) and feces (95%) (Dang, et al, 1992). An NRC report (NRC, NUREG-0941, 1983) on uranium dust exposure to workers concluded that the silica contained in uranium ore dust is a far greater worker health hazard than the radiological hazard of uranium. It was determined that if aerosol concentrations of silica are properly controled, the airborne concentration of radionuclides will be well below radiological limits (NRC, NUREG-0941, 1983).

Perhaps the most complex study to date on aerosolized uranium was the Capstone Study by USACHPPM. The study examined the depleted uranium (DU) aerosols generated inside the crew cab of M1 Abrams tanks hit by a DU round. The crew of the tank would receive a maximum of 10 mSv from the DU in the worst case scenario (Guilmette, et al, 2009). The worst case scenario for lifetime risk for lung cancer from the DU aerosols in the M1 Abrams tank was for staying in the tank hit by DU rounds for two hours. An increased risk of 0.42% was calculated which could be reduced significantly by using the ventilation system and reducing personnel time in the vehicle immediately after the DU round strikes the tank (U.S. Department of Energy, 1996; Hahn, et al, 2009).

A study of almost 19,000 uranium processing plant workers between 1943 and 1947 showed that there is no dose-response relationship between the risk of lung cancer death and lung dose

resulting from internal exposure to uranium dust. The odds ratio was 2.0 for employees to 0.25 Gy and higher, but the 95% confidence interval of 0.20 to 20 showed great uncertainty in the estimated odds ratio (Dupree et al, 1995). A French study of 2,709 male uranium processing plant workers (1960 to 2005) shows a non-statically significant relative risk for lung cancer with relative risk varying from 0.73 to 2.6 at the 95% confidence interval depending upon the model used and the solubility of the uranium (Canu, et al, 2010). A fifty year study of occupational exposure to depleted uranium showed no statistically significant cancer risk (McDiarmid, 2001).

There are multiple cases of worker inhalation of large quantities of uranium that resulted in reversible deterministic effects. One was an acute inhalation of 40 to 50 mg of non-enriched UF_6 by three uranium workers who showed no detectable deposition of uranium nor any medical impact (Kathren and Moore, 1986). An industrial accident in China resulted in powered UF_4 inhalation intake of 86.7 mg of enriched UF_4 with an assumed AMAD of 1 µm. The patient was treated, declared healthy and released after 30 days (Zhao and Zhao, 1990). Another worker in China received 3rd to 1st degree burns from a combination of inhalation of hot (108 °C) $UO_2(NO_3)_2$ Å6H_2O and UO_2 and UO_3. Like the worker who inhaled enriched UF_4, symptoms included dizziness, nausea and anorexia. One month post-accident, the patientôs laboratory results and prognosis was normal (Zhao and Zhao, 1990).

Ingestion

The principle route of uranium uptake by the public is typically through ingestion of uranium in or on food (Ahier and Tracy, 1995). Ingestion is also associated with aerosols found at uranium mills. Due to the very large particle sizes (10 μm median aerodynamic diameter) at uranium mills, very few if any uranium particles can be deposited in the pulmonary region of the lung (where long-term retention is possible) and are instead trapped in the upper regions of the respiratory tract and ingested (US NRC NUREG-0941, 1983).

Only 2 to 5% of ingested, soluble uranium is absorbed into the bloodstream from the intestines and the residual 95 to 98% is eliminated promptly. Of the small fraction of ingested uranium that is in the bloodstream, 90% is voided within one week. The remaining ~0.4% of the original ingested uranium is deposited in the kidneys (10%),bone (15%) and whole body (75%). The kidney clears its uranium burden within two weeks but the uranium in the bones takes 5 to 25 years to void (Bleise et al, 2003). An uptake of ~0.4% is supported by data from controlled studies on the fractional absorption of ingested uranium in humans that listed uptake values at less than 0.1% to a high as 6% with the normal values being 1% to 1.5% (Leggett and Harrison, 1995).

A number of mining companies have derived a natural uranium standard for uranium contaminated soil based upon the US EPA drinking water standard which is based on chemical toxicity (Pacific Northwest Laboratory, PNL-10065, 1994 and US NRC, NUREG-1391, 1991). The EPA drinking water standard is set at 0.06 mg/day for uranium (230 pCi/g, 8.5 Bq/g) (EPA, 2001). The EPA drinking water limit is defined for a resident farmer or industrial worker with chronic intake of uranium rather than acute.

Both chronic and acute cases of uranium intakes above recommended levels appear to cause physiologic changes that resolve over time. For example, a three year old child that had spent her entire life drinking water with 866 to 1,160 μg uranium per liter of water (EPA limit is 30 μg/L), as well as 1,040 mg arsenic/L and 15.61 pCi/L of radium had elevated creatinine and uranium excretion levels which resolved themselves after three months (Magdo et al, 2007). A patient ingested 15 g of uranium nitrate and had mild myocarditis that resolved in under six months and vomiting that resolved itself within 24 hours (Brugge et al, 2005). Five volunteers drank a grapefruit drink spiked with 100 μg of uranium nitrate and showed that increased creatinine (1-methylglycocyamidine) concentration in urine can be used as an indicator of increased uranium intake. The five volunteers suffered no ill effects and the uranium isotopic ratio was normal within hours and was at natural uranium levels within days (Karpas, et al, 1998). Finally, depleted uranium (DU) used in dental porcelain powders in Japan showed no negative health impacts (Nguyen, et al, 1995).

Nephrotoxicity

The threshold for kidney nephrotoxicity in humans has been reported to be 1 to 3 μg (7×10^{-4} to 2×10^{-3} pCi) uranium per gram of kidney tissue (Kocher, 1989 and Pacific Northwest Laboratory, PNL-10065, 1994). In contrast with this data, cattle kidneys have an average uranium concentration of almost 6×10^{-3} pCi of uranium per gram of kidney tissue (Table 14) with no ill effects upon the cattle.

Adult human beings appear to be extremely resistant to uranium contamination and suffer no histological or functional kidney toxicity even with implanted, insoluble DU fragments above the predicted nephrotoxic level (McClain et al, 2001). U.S. veterans with embedded fragments of depleted uranium (DU) were found to have elevated levels of uranium in their urine, but no obvious biological impact due to the uranium (Gwiazda, et al, 2004). A seven year study of 32 veterans with embedded DU showed no negative impacts due to the DU (McDiarmid, et al, 2000). After twelve years there was evidence of elevated levels of uranium in the veteranôs urine due to retained DU metal shrapnel fragments. Initially the study showed no loss of renal function and mixed results for genotoxicity, possibly in part due to the small cohort (McDiarmid, et al, 2006). Renal concentrations of depleted uranium in exposed Gulf War veterans seemed to eventually level off at 1 ppm after a period of six to ten years (Squibb, et al, 2005). With eventually seventy four Gulf War veterans enrolled in the study, there was a sustained suggestion

of a weak genotoxic consequence as measured at the HPRT (hypoxanthine-guanine phosphoribosyl transferase) locus due to the continuous DU exposure (McDiarmid, et al, 2007).

There has been one report of renal toxicity in uranium mill workers at a Colorado uranium mill (Thun, et al, 1985). No other reports of renal toxicity among workers or the public from uranium mining or milling were located. No uranium-specific kidney nephropathy has been found among the uranium workers (Russell, et al, 1996). A study of mortality among workers employed at a uranium processing plant between 1943 and 1947 showed no difference in lung cancer, bone cancer or leukemia rates among those who worked in high-uranium dust areas and in ñcleanò areas (Polednak and Frome, 1981).

Uranium in Produce and Livestock

Since the principle route of uranium uptake by the public is typically through ingestion of uranium in or on food (Ahier and Tracy, 1995), it is useful to examine how uranium in contaminated soils concentrates in produce and livestock. The ATSDR (Agency for Toxic Substances and Disease Registry, 2011) estimated that the daily intake of uranium from food is 0.6 to 1.0 pCi/day (0.9ï 1.5 ε g/day). The level of toxicity for uranium could be inferred from the health status of the flora and fauna that have ingested various amounts of these primary and secondary uranium ores for their entire lifetime. The radioecology of the uranium mills (Landa,

2004) and areas with U-nat should be taken into account in deciding a soil contamination limit for U-nat (Wicker and Schultz, 1982).

Overall, agricultural crops vary considerably in their uranium uptake, but as a thumb rule for agricultural crops, the edible leaves accumulate ~10% of the uranium and the remaining ~90% of the uranium uptake is by the roots (Soudek et al, 2011), with an average transfer fraction of 10^{-4}. The transfer fractions (TF) were from 10^{-2} to 10^{-5} for the zucchini and watermelon tested at Khan Al-Zabeeb (Al-Kharouf, et al, 2008). In sites where the uranium content is almost two orders of magnitude higher than the nominal 30 pCi/g (1.1 Bq/g) NRC limit, the vegetables grown absorb far less uranium and are declared safe to eat. When using a DCGL for a garden or agricultural site, the concentration of 1,300 pCi/g (48 Bq/g) natural uranium per gram of soil could be the limit for growing vegetables for human consumption based upon the results.

Livestock and Livestock Feed

The uranium mine tailings in a nursery increased the root and shoot growth of reed canary grass and birdsfoot trefoil (Watkin and Winch, 1974).

Vegetables from home gardens and dairy products (Table 9) from cattle grazing on pasture in the Canas de Stenhorim area of Portugal near uranium mill tailings piles showed poor uptake of uranium from the soil (Carvalho et al, 2009) and compares well to the natural uranium and DU uptake by plants and livestock (Figures 12 and 13).

Table 9, Pasture land, lettuce and dairy grown near a uranium tailings pile in Portugal.

	Bq/g	pCi/g
Milling pile	2.5	69
Sludge pond	41.6	1127
Background	0.23	6
Lettuce	0.15	4
Pasture	7×10^{-3}	0.2
Milk	4×10^{-3}	0.1

Table 10, Uranium content in plants growing in a phosphogypsum waste heap in Poland

		mg U-238 / kg wet weight		pCi U-238 / g weight weight		
	Location on plant	Private Garden	Phospho-gypsum waste heap	Private Garden	Phospho-gypsum waste heap	Ratio of Phospho-gypsum waste heap vs. Private Garden
Dandelion	Above ground	0.08	0.37	5.33×10^{-2}	2.47×10^{-1}	4.6
	Near ground	0.08	0.42	5.33×10^{-2}	2.80×10^{-1}	5.3
	Root	0.13	0.59	8.67×10^{-2}	3.93×10^{-1}	4.5
Silverweed	Above ground	0.08	0.46	5.33×10^{-2}	3.07×10^{-1}	5.8
	Near ground	0.09	0.48	6.00×10^{-2}	3.20×10^{-1}	5.3
	Root	0.10	0.57	6.67×10^{-2}	3.80×10^{-1}	5.7
Common sedge	Above ground	0.14	0.95	9.33×10^{-2}	6.33×10^{-1}	6.8
	Near ground	0.16	1.45	1.07×10^{-2}	9.67×10^{-1}	9.1
	Root	0.17	2.45	1.13×10^{-1}	1.63	14.4

The phosphogypsum waste heap (150 Bq of uranium per kg of soil, 0.15 Bq/g, 4 pCi/g) of sedimentary phosphoric rock in Wislika, Poland was studied for uptake of uranium (Borylo and

Skwarzec, 2011). Root uptake of uranium was highest in the Common Sedge root (1.6 pCi/g, 6×10^{-2} Bq/g), but there remained two orders of magnitude variation between the tested plants. There was a 4.6 to 14.4 fold increase in uranium uptake from plants growing on the phosphogypsum waste heap as compared to a private garden. The average transfer fraction (TF) was approximately 10^{-1}.

Vegetables and Fruit

Vegetables were grown in contaminated soil from a closed uranium mine (64ï 252 mg/kg, 158 mg/kg average, 57 pCi/g, 2.1 Bq/g) and the maximum uranium concentration in the edible parts was reduced well over a thousand-fold in some cases (Table 11). Although uranium in soil, irrigation water, and vegetables was higher than the average, the health risk from consumption of vegetables grown in uranium mill tailings were reported to not pose adverse effects for consuming these vegetables (Neves and Abreau, 2009).

Table 11, Reduction in uranium content from soil to edible plant

Vegetable	µg/kg	Bq/g	pCi/g	Reduction from 1.58×10^{5} µg/kg in soil
Lettuce	234	2.9×10^{-3}	7.86×10^{-2}	1.48×10^{-3}
Green Beans	30	3.7×10^{-3}	1.01×10^{-2}	1.90×10^{-4}
Potatoes	4	5.0×10^{-4}	1.34×10^{-2}	2.53×10^{-5}
		Average reduction		5.65×10^{-4}

Due to the high carbonate content in the water in Darya City, Syria, soluble uranium carbonate complexes form easily and the vegetables in Darya City had the highest uranium content (Al-Masri, et al, 2004). The transfer fractions (TF) can vary from as high as 10^{-1} to as low as 10^{-5}, depending upon location and type of plant.

Table 12, Uranium content in Syrian foods

Food	μg U/kg dry wt	Bq/g	Equivalent pCi/g
Milk	2.2 to 10.5	2.7×10^{-5} to 1.3×10^{-4}	7.4×10^{-4} to 3.5×10^{-3}
Canadian wheat	5	6.3×10^{-5}	1.7×10^{-3}
Yellow corn	51	6.3×10^{-4}	1.7×10^{-2}
Grapes	4	4.8×10^{-5}	1.3×10^{-3}
Banana	95	1.2×10^{-3}	3.2×10^{-2}
Mushrooms	128	1.6×10^{-3}	4.3×10^{-2}

The foods in Syria have uranium contents that are lower than the plants cited in the previous graphs from mines in Wyoming, South Dakota, and Nebraska (Figure 12).

Khan Al-Zabeeb, Jordan is an irrigated agricultural area that rests above a superficial uranium deposit that ranges from 1186 ppm (400 pCi/g, 14.8 Bq/g) to 4,000 ppm (1,344 pCi/g, 49.6 Bq/g) in the soil. The green parts (leaves, stems, and roots) of agricultural crops in the area tend to accumulate uranium about two orders of magnitude higher than the fruits (Al-Kharouf, et al, 2008). The transfer fraction (TF) from uranium concentration from soil to plant in Khan Al-Zabeeb is between 10^{-4} and 10^{-5}, which compares well to the value of 6×10^{-4} (Neves and Abreau,

2009) but not well with the 10^{-1} TF from the Poland study of natural plant life growing on the phosphogypsum waste heap (Borylo and Skwarzec, 2011).

A study of cereal crops in the Qena region of Upper Egypt showed a similar uptake ratio, and the average uranium concentration was 0.67 Bq natural uranium per kg of edible seeds (1.8×10^{-2} pCi/g, 6.6×10^{-4} Bq/g) (Harb and Michel, 2009).

For tomato plants, the rate of uranium uptake increases with age and concentration of uranium in the soil. The rate of uranium uptake levels off at 500 ppm (168 pCi/g, 6.2 Bq/g) suggesting that uranium might have a threshold at which plants no longer require more uranium (Kaur, et al, 1988). An upsurge in the uranium concentration in vegetables was correlated with increasing concentrations of uranium in irrigation water rather than soil. The percentage of uranium uptake by the rice and vegetables decreased with increasing concentrations of uranium (Lakshmanan and Venkateswarlu, et al, 1988).

In Germany, leafy plants (chives, parsley, meadow red clover, white clover and lettuce) had the highest concentration of uranium but tubes, thick parts of the stalks, fruits and grains had the least amount of uranium (Table 13). The Erzgebirge/Sachsen area of Germany has mined uranium ore for over 500 years, and while lung cancer (ñSchneeberg diseaseò) is a result of radon inhalation, no negative impacts due to uranium have been cited (Meinrath, et al, 2003 and Tomasek, et al, 1994).

Table 13, Uranium content in plants grown in uranium mining areas and control areas in Germany

	µg/kg		pCi/g		
Plant species	Control	Uranium mining area	Control	Uranium mining area	Ratio of Uranium Mining Area vs. Control
Wheat grain	0.6	1.20	3.87×10^{-4}	8.00×10^{-4}	2.07
Rape seed	0.7	2.20	4.73×10^{-4}	1.47×10^{-3}	3.10
Apple	2.7	2.80	1.80×10^{-3}	1.87×10^{-3}	1.04
Potatoes, peeled	2.3	2.90	1.53×10^{-3}	1.93×10^{-3}	1.26
Onion	5.2	4.30	3.47×10^{-3}	2.87×10^{-3}	0.83
Tomato	5.2	5.00	3.47×10^{-3}	3.33×10^{-3}	0.96
French beans	3.1	8.10	2.07×10^{-3}	5.40×10^{-3}	2.61
Carrots	4.4	8.20	2.93×10^{-3}	5.47×10^{-3}	1.86
Cucumber	7.0	8.50	4.67×10^{-3}	5.67×10^{-3}	1.21
Chives	10.0	29.00	6.67×10^{-3}	1.93×10^{-2}	2.90
Parsley	28.0	54.00	1.87×10^{-2}	3.60×10^{-2}	1.93
Meadow red clover	7.4	57.00	4.93×10^{-3}	3.80×10^{-2}	7.70
White clover	15.0	68.00	1.00×10^{-2}	4.53×10^{-2}	4.53
Lettuce	34.0	73.00	2.27×10^{-2}	4.87×10^{-2}	2.15

The food in Germany was tested (Anke et al, 2009) and the uranium concentration was low in butter and other refined foods and highest in mushrooms (Tables 12 & 14). Reviewing results from Germany in 2009 (Anke et al, 2009) and USA in 1967 (Welford and Baird, 1967), the values in Germany are at least an order of magnitude higher.

Table 14, Uranium content in food tested in Germany

Food Stuff	U µg/kg dry matter	pCi U / kg dry matter
Butter	0.7	4.67×10^{-4}
Pork	1.5	1.00×10^{-3}
Chicken	2.6	1.73×10^{-3}
Tomatoes	3.0	2.00×10^{-3}
Camembert cheese	6.3	4.20×10^{-3}
Sardines	6.7	4.47×10^{-3}
Carrots	8.0	5.33×10^{-3}
Kidney, cattle	8.8	5.87×10^{-3}
Dwarf beans	8.9	5.93×10^{-3}
Table salt	10.0	6.67×10^{-3}
Cucumber	12.0	8.00×10^{-3}
Hen's egg	16.0	1.07×10^{-3}
Pepper, sweet	19.0	1.27×10^{-2}
Lettuce	39.0	2.60×10^{-2}
Asparagus	53.0	3.53×10^{-2}
Mixed mushrooms	105.0	7.00×10^{-2}

The northern Australian Alligator Rivers Region (ARR) has high uranium content in the soil. The Ranger uranium mine and several former and proposed mines operate or operated there. Some of the native plants that the Australian Aboriginal people eat were growing in the uranium mine tailings piles or dry creek beds adjacent to the abandoned uranium mines. These foods were harvested and eaten. The *vigna lanceolatas* (ñangourmakò, pencil yams) growing in the uranium mill tailings pile near the Rock Hole Mine and South Alligator mill were harvested and eaten in this study (Ryan, et al, 2005).

The transfer fraction from soil to plant was normally on the order of 10^{-2} to 10^{-5}, which compares well to the TF found at Khan Al-Zabeeb (Al-Kharouf, et al, 2008).

In Jharkhand, India a study of the uptake of all radionuclides from vegetables was 1340 pCi per year (49.58 Bq per year) to give a dose of 11.51 μSv per year, well below the 1 mSv guideline suggested by the ICRP (Giri et al, 2010).

In summary, there is wide variation in uranium concentration and uptake due to location, plant type, type of food material (milk, eggs, cattle kidney, etcé). Only one food substance was found that concentrated uranium over 1 pCi uranium per gram: Common Sedge leaves and root, growing on a phosphogypsum waste heap.

RESULTS

Given the wide range possible for uranium concentrations in soils (due to a combination of primordial and human use) variation in limits appears inevitable. The regulators appear to have adjusted limits site by site, in accordance with ALARA, without developing an overall limit for sites. Regardless of the date, the limit for uranium contamination in soil is higher for the more contaminated sites, and both the limits and contamination levels vary by orders of magnitude.

Trends in uranium limits since 1980

The trend for limits over time is that the number of limits increases. The limits appear to increase slightly over time, but when a trend is plotted the correlation is poor (Figure 19).

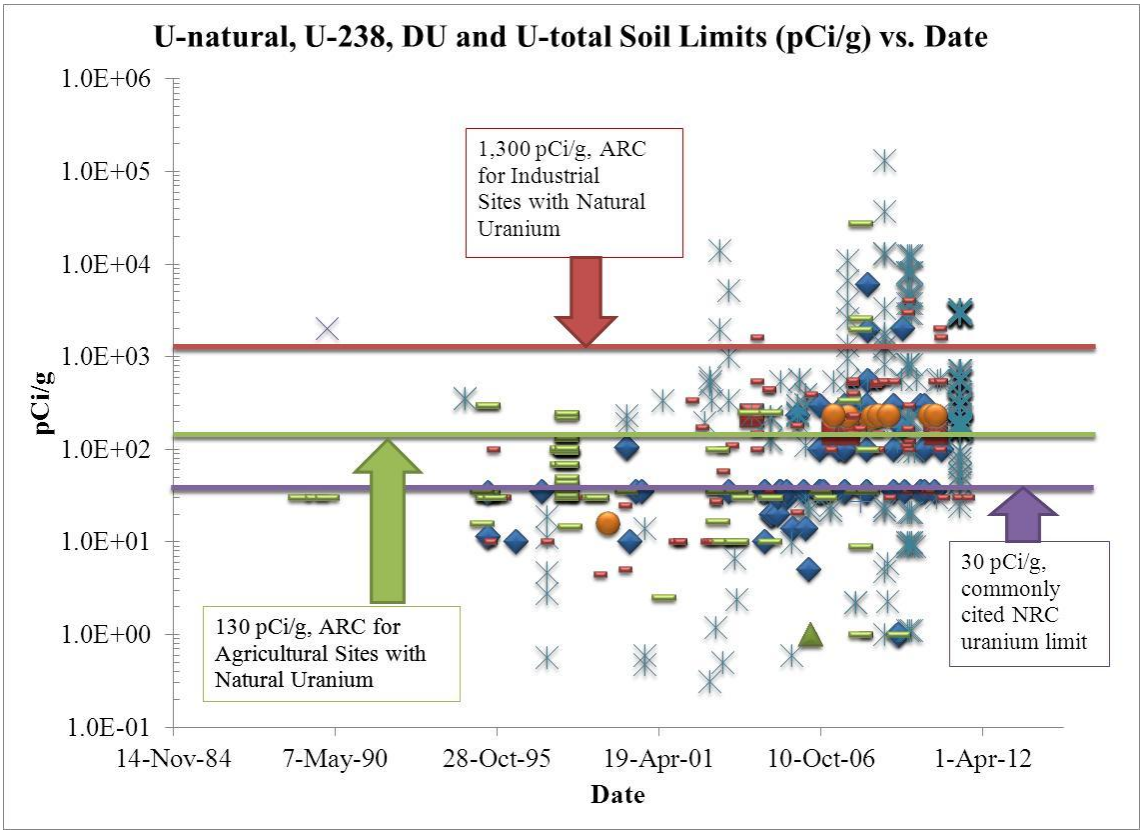

Figure 19, Non-enriched Uranium Soil Limits vs. Date, Nationwide, USA

The non-enriched uranium (Figure 19) limits used at the various sites span six orders of magnitude, with the statistics featured below (Table 15).

Table 15, Statistics for Non-enriched Uranium Values

	Mean	Standard Deviation	Median	Mode	Data Points
pCi/g	1193	5792	169	35	654
Bq/g	44.0	213.7	6.2	1.3	

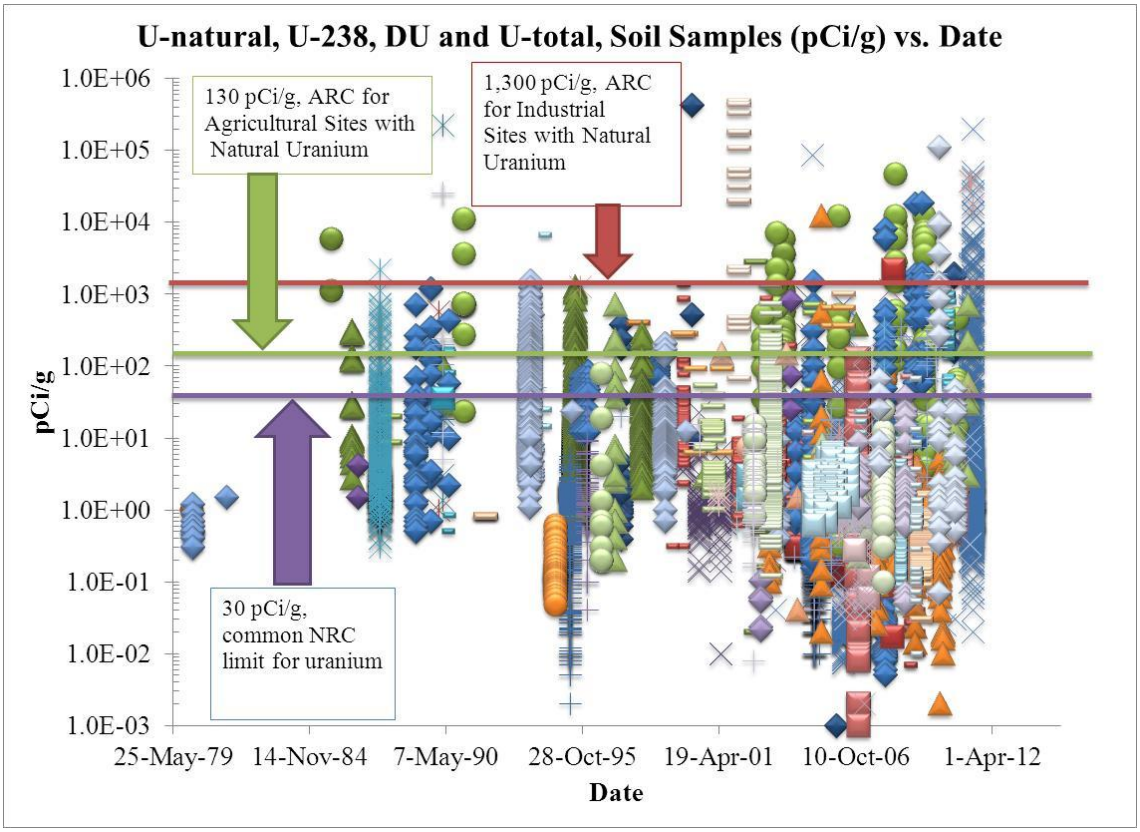

Figure 20, Non-enriched Uranium Soil Concentration Values vs. Date, Nationwide, USA

The non-enriched uranium (Figure 20) soil concentration values span nine orders of magnitude, with the statistics featured below (Table 16).

Table 16, Statistics for Non-enriched Uranium soil concentration values

	Mean	Standard Deviation	Median	Mode	Data Points
pCi/g	241	7464	2	7	16569
Bq/g	8.9	275.4	0.1	0.3	

DISCUSSION

Calculation of Uranium Intake in Animal Models

While animal models are not perfect simulations for human beings, as an LD_{50} from human intake has not be established, animal models are used as human proxies. As noted earlier, the chemical form of uranium in soil could be one of many keys to biological availability of uranium and incorporation into tissues. All calculations for uptake of uranium are assuming long term chronic consumption and equilibrium is assumed. Given the various chemical forms of uranium, the uptake is highest for uranium nitrate (1%). In general, as the chemical becomes less soluble, the uptake is reduced. The fractional uptake of uranium depends upon the chemical form ingested and the fasting state. If the subject is fasting, the uptake increases ten-fold from a fed state.

Table 17, Uranium Chemical Uptake Percent (Leggett and Harrison, 1995)

	Uranium Uptake Ratio			
Compound	Mice	Rats	Dogs	Hamsters
$UO_2(NO_3)_2$ $6H_2O$	1	1	1	1
UO_2F_2	1	1	1	
$Na_2U_2O_7$	1			
UO_4	0.5			
UO_3	0.5			
UCl_4	0.1			
U_3O_8	0.01		0.01	
UO_2		0.01	0.01	0.1
UF_4	0.003	0.02		

The Transfer Fraction (TF) from soil to plant (Al-Kharouf, et al, 2008) and the Concentration Ratio (CR) from plant to plant eater (herbivore or omnivore) who eats the leaves (10% uptake) (Soudek et al, 2011), the uptake from the highest contaminated site (4.82×10^{5} pCi/g, 1.8×10^{4} Bq/g, White Mesa, Utah) (US NRC, ADAMS # ML030450294) results in a tissue concentration of uranium that is comparable to the uranium content in healthy animals (Figure 21). It could be noted that the only plant material found with over 1 pCi uranium per gram was Common Sedge leaves and root, growing on a phosphogypsum waste heap.

$$\text{Uptake} = \left(\begin{matrix}\text{Transfer}\\ \text{Fraction}\end{matrix}\right)\left(\begin{matrix}\text{Concentration}\\ \text{Ratio}\end{matrix}\right)\left(\begin{matrix}\text{Soil}\\ \text{Concentration}\end{matrix}\right)$$

$$\text{Uptake} = (\text{TF})(\text{CR})(\text{SC})$$

$$\text{Uptake} = \left(10^{-4}\right)\left(10^{-1}\right)\left(4.82\times10^{5}\ \frac{\text{pCi}}{\text{g}}\right) = 4.8\frac{\text{pCi}}{\text{g}}$$

Figure 21, Theoretical Maximum Uptake of U-238 in plants at the highest uranium contaminated site in the US.

If cattle were grazing upon grassland over a uranium contaminated mill tailings site, the concentration in their bones (uranium is concentrated in the bones, Bleise et al, 2003) would not exceed 5 pCi/g (0.2 Bq/g) (Fig. 17). Humans do not typically eat the bones of cattle, thus the concentration could be further reduced at least two orders of magnitude, since the Flesh to Whole Body Ratio (FWB) is 10^{-2} (Leggett and Harrison, 1995) (Fig. 18). The calculation of approximately 5×10^{-2} pCi/g (2×10^{-3} Bq/g) in animal meat raised on grassland over contaminated soil compares well to the concentration of uranium in animal products from Germany (Table 14).

$$\text{Uptake} = \begin{pmatrix}\text{Flesh to}\\ \text{Whole Body}\\ \text{Ratio}\end{pmatrix}\begin{pmatrix}\text{Transfer}\\ \text{Fraction}\end{pmatrix}\begin{pmatrix}\text{Concentration}\\ \text{Ratio}\end{pmatrix}\begin{pmatrix}\text{Soil}\\ \text{Concentration}\end{pmatrix}$$

$$\text{Uptake} = (\text{FWB})(\text{TF})(\text{CR})(\text{SC})$$

$$\text{Uptake} = \left(10^{-2}\right)\left(10^{-4}\right)\left(10^{-1}\right)\left(4.82\times10^{5}\ \frac{\text{pCi}}{\text{g}}\right) = 4.82\times10^{-2}\ \frac{\text{pCi}}{\text{g}}$$

Figure 22, Uptake of U-238 in meat

For direct ingestion of uranium, human uptake of uranium from consuming meat is 1.0 to 1.5% for adult humans (Leggett and Harrison, 1995) (Fig. 22). While the ratio has been reduced from plants, to herbivore flesh, the ratio is further reduced when the human eats the meat.

$$\text{Uptake} = \begin{pmatrix}\text{Human}\\ \text{Uptake}\\ \text{Ratio}\end{pmatrix}\begin{pmatrix}\text{Flesh to}\\ \text{Whole Body}\\ \text{Ratio}\end{pmatrix}\begin{pmatrix}\text{Transfer}\\ \text{Fraction}\end{pmatrix}\begin{pmatrix}\text{Concentration}\\ \text{Ratio}\end{pmatrix}\begin{pmatrix}\text{Soil}\\ \text{Concentration}\end{pmatrix}$$

$$\text{Uptake} = (\text{HUR})(\text{FWB})(\text{TF})(\text{CR})(\text{SC})$$

$$\text{Uptake} = \left(10^{-2}\right)\left(10^{-2}\right)\left(10^{-4}\right)\left(10^{-1}\right)\left(4.82\times10^{5}\ \frac{\text{pCi}}{\text{g}}\right) = 4.82\times10^{-4}\ \frac{\text{pCi}}{\text{g}}$$

Figure 23, Uptake of U-238 in humans from consuming uranium contaminated meat.

There are other contaminates in a uranium mill tailings pile in addition to U-238 which are not included in this analysis, but a comparison of the calculated value of approximately 5×10^{-4} pCi/g (2×10^{-5} Bq/g) (Figure 23) vs. the actual value of uranium content in human flesh 4×10^{-4} pCi/g (1.5×10^{-5} Bq/g) (Table 18) demonstrates that this mathematical model is reasonable.

Table 18, Uranium content in Humans

	μg U	μg U per kg wet weight	pCi U per g wet weight	Ratio
Skeleton	69.6	0.99	3.31×10^{-4}	0.81
Flesh	16.7	0.24	7.95×10^{-5}	0.19
Whole Body	86.3	1.23	4.11×10^{-4}	1.00

For comparison, the concentration of uranium in human tissue is 100 to 125 μg (4.8×10^{-4} pCi/g to 5.8×10^{-4} pCi/g, 1.8×10^{-5} Bq/g to 2.1×10^{-5} Bq/g) per person (Table 18) (Hamilton, 1972). A later study noted that the uranium content in human bone ash varies by location. The extremes were natives of Yugoslavia at 0.5 μg uranium per kg of human bone ash and Nigeria at 50 μg uranium per kg of human bone ash (Fisenne, et al 1988).

Legal Aspects

As an attorney with the U.S. Department of Justice pointed out, the scientific uncertainty regarding uranium mining health risks pose a difficulty when working with the legal system (Monson, 1983). Published science could support uranium soil contamination limits. In 1992 OSHA was reprimanded by the US Supreme Court for making limits without good science to back it up (AFL/CIO vs. OSHA, U.S. Court of Appeals, 11th Cir Court, July 7, 1992). The case summary follows:

CASE SUMMARY:

PROCEDURAL POSTURE: In consolidated appeals, petitioner industries and a union challenged both the procedure used by respondent Occupational Safety and Health Administration to generate the Air Contaminants Standard, 29 C.F.R. § 1910.1000, and respondent's findings on specific substances included in the new standard. Pursuant to 28 U.S.C.S. § 2112(a), all petitions for review of the standard were transferred to the court.

OVERVIEW: Respondent Occupational Safety and Health Administration issued its Air Contaminants Standard, 29 C.F.R. § 1910.1000, a set of permissible exposure limits for 428 toxic substances. Petitioner industries and a union challenged both the procedure used to generate the multi-substance standard and respondent's findings on numerous specific substances included in the new standard. The court held that the analytical approach used by respondent in promulgating the revised standard was so flawed that it could not stand. Respondent inappropriately treated this as a "generic" rulemaking, resulting in a set of 428 inadequately supported standards. Respondent had lumped together substances and affected industries and provided such inadequate explanation that it was virtually impossible for a reviewing court to determine if sufficient evidence supported the conclusions. Respondent had not sufficiently explained or supported its threshold determination that exposure to the substances at previous levels posed a significant risk of material health impairments or that the new standard eliminated or reduced that risk to the extent feasible. The court vacated the revised standard, and remanded.

OUTCOME: The court vacated the revised standard, and remanded to respondent Occupational Safety and Health Administration because its overall approach to the rulemaking was flawed. Respondent had not sufficiently explained or supported its threshold determination that exposure to the substances at previous levels posed a significant risk of material health impairments or that the new standard eliminated or reduced that risk to the extent feasible.

Figure 24, Case Summary, AFL/CIO vs. OSHA, U.S. Court of Appeals, 11th Cir Court, July 7, 1992

OSHA regulates the uranium limits for workers for general industry, maritime and construction. Any legal ruling against OSHA could be applied to the NRC because both organizations regulate hazards to workers.

https://www.osha.gov/dts/chemicalsampling/data/CH_274900.html

The conclusions found by the 11th circuit court were rather blunt.

IV. CONCLUSION

It is clear that the analytical approach used by **OSHA** in promulgating its revised Air Contaminants Standard is so flawed that it cannot stand. **OSHA** not only mislabeled this a "generic" rulemaking, but it inappropriately treated it as such. The result of this approach is a set of 428 inadequately supported standards. **OSHA** has lumped together substances and affected industries and provided such inadequate explanation that it is virtually impossible for a reviewing court to determine if sufficient evidence supports the agency's conclusions. The individual substances discussed in this opinion are merely examples of what is endemic in the Air Contaminants Standard as **[**68]** a whole.

OSHA does have the authority to set priorities for establishing standards under the OSH Act. *See* 29 U.S.C. § 655(g). That priority-setting authority permits **OSHA** to combine rulemaking for multiple substances in one rulemaking, to limit the scope of this rulemaking in a rational manner, and to defer issuance of regulations for monitoring and medical surveillance until a later rulemaking. It does not, however, give **OSHA** blanket authority to pick and choose what statutory requirements it will follow. The OSH Act mandates that **OSHA** promulgate the standards that "most adequately" assure that workers will not be exposed to significant risks of material health impairment "to the extent feasible" for the affected industries. Further, section 6(e) and caselaw require **OSHA** to adequately explain its determinations. Section 6(b) of the Act does not provide an exception to these requirements for administrative convenience. The only exceptions to the strict statutory criteria are the start-up provisions of section 6(a), the applicability of which has long since passed, and the emergency provisions of section 6(c), neither of which are implicated in this case.

Figure 25, Conclusion, AFL/CIO vs. OSHA, U.S. Court of Appeals, 11th Cir Court, July 7, 1992

In regards to workers, OSHA and NRC have the same responsibilities to use good science to back up their actions.

Evidence > Procedural Considerations > Burdens of Proof > Ultimate Burden of Persuasion
Labor & Employment Law > Occupational Safety & Health > Administrative Proceedings > Rulemaking
Labor & Employment Law > Occupational Safety & Health > Burdens of Proof

[HN10] The Supreme Court has interpreted 29 U.S.C.S. § 652(8) to require that, before the promulgation of any permanent health standard, the Occupational Safety and Health Administration (**OSHA**) make a threshold finding that a significant risk of material health impairment exists at the current levels of exposure to the toxic substance in question, and that a new, lower standard is therefore reasonably necessary or appropriate to provide safe or healthful employment and places of employment. **OSHA** is not entitled to regulate any risk, only those which present a "significant" risk of "material" health impairment. **OSHA** must therefore determine: (1) what health impairments are "material," and (2) what constitutes a "significant" risk of such impairment. Moreover, **OSHA** ultimately bears the burden of proving by substantial evidence that such a risk exists and that the proposed standard is necessary.

Figure 26, Burden of Proof, AFL/CIO vs. OSHA, U.S. Court of Appeals, 11th Cir Court, July 7, 1992

The Supreme Court interpretation states that OSHA ñultimately bears the burden of proving by substantial evidence that such a risk exists and that the proposed standard is necessary.ò Like OSHA, the NRC is a federal regulatory agency that submits limits. OSHA submits limits for worker intake of uranium (STELs and PELs) and the NRC has both worker and environmental limits.

Financial Cost

From NUREG-1496, Vol. 3, Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities, July 1997:

> There is very limited information on the distribution of radionuclide contamination with depth into the soil column or volume at uranium fuel fabrication plants. Data available on three DOE Formerly Utilized Sites Remedial Action Program (FUSRAP) uranium facilities indicate that the volume of contaminated soil requiring remediation increases by a factor of 3.4 to 14 when the residual criteria are decreased from 130 to 13 pCi/g (DOE, 1994a).

Figure 27, Volume of Contaminated Soil Increases 3.4 to 14 Fold

As the limit is reduced, the volume of material that must be processed as radiological waste increases, and this increases the financial cost.

Site soil has been estimated to be potentially contaminated above 30 pCi U/g, at depths ranging from near-surface to >25 feet. Uranium contamination concentrations of 24 - 300 pCi U/g were found beneath part of Building 3 and the east end of Building 4, at depths from 6 - 96 inches. The riverbank soils are also being characterized; three samples taken from near the plant exceeded 30 pCi U/g. All materials known to be contaminated in excess of 2,000 pCi/g were removed from the site prior to December 31, 1991. The median concentration of uranium in the soils is less than 200 pCi/g (NRC, 1993). A surface area of approximately 150,000 ft^2 is estimated to be contaminated to varying degrees with uranium. A total of 665,000 ft^3 of soil contaminated to greater than 30 pCi/g have been excavated and disposed of offsite at the Envirocare disposal facility (Carlson, 1994).

The Ventron Corporation plant formerly performed uranium work in three buildings for the Atomic Energy Commission (AEC) and requires remediation of thorium-contaminated soils and buildings. Preliminary information provided by the DOE on the estimated ratio of volumes of contaminated soil for different cleanup criteria is as follows (DOE, 1994a):

Cleanup Criteria (pCi/g)	Contaminated Soil Volume Ratio (relative to 130 pCi/g)
130	1
80	1.23
39	1.6
30	2.27
20	2.76
13	3.38
4	4.5

Figure 28, Cleanup Criteria vs. Contaminated Soil Volume

The U.S. Department of Energy is required by the Energy Policy Act of 1992 (EPAct) to report triennially to the U.S. Congress on the recommendations regarding reauthorization and management of the Uranium Enrichment Decontamination and Decommissiong (UED&D) Fund. The fundôs primary purpose is to cleanup the USAôs three gaseous diffusion plants (GDPs) at (1) East Tennessee Technology Park (ETTP) in Oak Ridge, (2) Paducah GDP in Paducah, Kentucky and the Portsmouth GDP near Piketon, Ohio. As of 2007, the cleanup cost was estimated to be between $8 billion and $21 billion, in addition to the $4.1 billion dollar current balance (U.S. Department of Energy, 2007). On a smaller scale, the estimated cost for remediating each contaminated structure in the Navajo Nation is $100,000 to $300,000 per structure for 110 structures (House Committee on Oversight and Government Reform, 2008).

Based upon NUREG-1496, there is a 2.27 fold decrease in the amount of material shipped if the regulatory level is increased from 30 pCi/g (1.1 Bq/g) to 130 pCi/g (4.8 Bq/g). Therefore increasing the limit could save the US taxpayers $4.5 billion to $12.0 billion, using the DOE data from the 2007 report to Congress, while the postulated risk to human health is negligible. In addition with the closure of Yucca Mountain (EPA, 1999) and other radioactive disposal sites, costs will only increase, making these estimates possibly the best case scenario. The resultant risk increase by changing the limit to 130 pCi/g (4.8 Bq/g) is postulated to pose negligible health risks based on previous data and estimates presented.

Suggested Uranium Soil Contamination Limits

Computation of Alternate Release Criteria (ARC) takes into account the chemical toxicity (Pacific Northwest Laboratory, PNL-10065, 1994 and US NRC, NUREG-1391, 1991) and the uptake of uranium compounds based upon Table 17. The most common uptake percentages for humans and animals are used in Table 18 to obtain uptake ratios for the major uranium compounds (Table 19).

Table 19, Ratios for Biological Impact of Non-enriched Uranium. Larger magnitude numbers indicate higher uptake.

Compound	U_3O_8	UF_4	UCl_4	UO_2	UO_2 + UO_3	UO_4	UO_3	$UO_2(NO_3)_2$ $6H_2O$	UO_2F_2	Na_2 U_2O_7
Standard Ratio	0.01	0.02	0.1	0.1	0.3	0.5	0.5	1	1	1

Natural uranium is mostly $UO_2 + UO_3$, and the ratio used in Table 19 for natural uranium is an average between UO_2 and UO_3. Table 19 illustrates that compounds to the right of $UO_2 + UO_3$ have a higher uptake ratio and therefore a higher impact upon biological system. Compounds to the left of $UO_2 + UO_3$ have a lower impact on biological systems. A sample calculation follows:

$$\frac{\left(\frac{1{,}300\,\text{pCi}}{\text{g}}\right)_{\substack{\text{Uranium Concentration} \\ \text{in Khan Al-Zabeeb,} \\ \text{Jordan}}}}{\left((0.02)_{\text{Uptake Ratio for } UF_4} \Big/ (0.3)_{\text{Uptake Ratio for U-nat}}\right)} = 19{,}500\,\frac{\text{pCi } UF_4}{\text{g}}$$

Figure 29, Sample Calculation for ARC

The basis for values in Table 20 are the natural uranium concentrations found in agriculturally viable areas of the world. The concentration of natural uranium in phosphate fertilizer used for gardens and agricultural areas can be as high as 130 pCi/g (4.8 Bq/g) (ATSDR, 2011).

The industrial limit (Table 20) for natural uranium is based upon the irrigated agricultural area of Khan Al-Zabeeb, Jordan (Al-Kharouf et al, 2008). Uranium soil concentrations of up to 1,344 pCi/g (49.6 Bq/g) elicited no deleterious effects on the farming population of Jordan and produced healthy crops. Since soil exposures during farming are expected to be in excess of industrial workers, no deleterious human effects are expected in workers.

Table 20, Chemically based Alternate Release Criteria for Non-enriched Uranium Compounds

	pCi U-238 per gram at the site		
	Agricultural / Garden	Public Access	Industrial
$UO_2(NO_3)_2\ 6H_2O$	3.9×10^{1}	1.0×10^{2}	3.9×10^{2}
UO_2F_2	3.9×10^{1}	1.0×10^{2}	3.9×10^{2}
$Na_2U_2O_7$	3.9×10^{1}	1.0×10^{2}	3.9×10^{2}
UO_4	7.8×10^{1}	2.0×10^{2}	7.8×10^{2}
UO_3	7.8×10^{1}	2.0×10^{2}	7.8×10^{2}
U-nat	1.3×10^{2}	3.4×10^{2}	1.3×10^{3}
DU	1.3×10^{2}	3.4×10^{2}	1.3×10^{3}
UCl_4	3.9×10^{2}	1.0×10^{3}	3.9×10^{3}
UO_2	3.9×10^{2}	1.0×10^{3}	3.9×10^{3}
UF_4	2.0×10^{3}	5.0×10^{3}	2.0×10^{4}
U_3O_8	3.9×10^{3}	1.0×10^{4}	3.9×10^{4}

CONCLUSIONS

The variation in uranium concentration in soil and promulgated limits for uranium concentration in soil nationwide spans orders of magnitude. Based on ADAMS documents, the NRC appears to set uranium soil contamination limits based upon simple solubility as well as local uranium concentrations, and ALARA methods used to determine the uranium soil contamination limits. The uptake by plants and animals of uranium from soil appears to be limited to 1 pCi/g (3.7×10^{-2} Bq/g), regardless of the soil concentration, thus limiting human and animal intake via this pathway.

Currently, farmers are growing crops in soils containing natural uranium concentrations well in excess of current limits with no documented deleterious effects (Al-Kharouf, et al, 2008). A thumb rule of 10^{-4} can be used as a reduction factor from soil to plant when assessing uranium uptake by plants in soil. This transfer fraction (TF) effectively renders most plant material safe for consumption in regards to uranium intake via the plant pathway.

The ALARA concept can apply to chemical toxins, but given that a chemical toxin sometimes is a required nutrient at a lower dose, ALARA does not always apply. The type of chemical compound, as well as the level of chemical dosing, makes the chemical impact negligible,

helpful, or harmful. Almost 500 years ago this concept was written down, and itôs important for the health physicist to widen the focus beyond the radiological hazard.

> ñAll things are poison, and nothing is without poison; only the dose permits something not to be poisonous. ñ ï Paracelsus (1536 AD)

It is easy for the health physicist to look purely at the simple solubility of uranium compounds to guide the limits and warnings. While human beings are mostly water, we are more than merely a glass of water. While solubility is important when it comes down to the chemical toxicity of uranium, the whole person could be considered in relation to the particular uranium chemical. And this is not a new concept:

> ñIf we want to make a statement about a man's nature on the basis of his physiognomy, we must take <u>everything</u> into account; it is in his distress that a man is tested, for then his nature is revealed. ñ -Paracelsus (1536 AD)

Prior to Gulf War I, health physicists DU was not considered a health issue because the chemical form of DU used by the Department of Defense is not very soluble in water. The scientific consensus was that the body could create a cyst around the DU particles so there could be little DU in the blood stream or urine. After more than 35 friendly fire victims with DU embedded in

them, it was easily demonstrated that bodily fluids are much more likely to dissolve DU than simple water (Gwiazda, et al, 2004).

It is important for the health physics community to reach out worldwide and enlist the aid of the toxicologists, chemists, biochemists, agriculture specialists, medical doctors, and veterinarians in determining how to regulate the chemical hazards of the various uranium chemicals. Uranium is far more than radiological dose, and a broad-based approach to this complicated system of chemicals is warranted.

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APPENDIXES

Appendix A: Cited files from the NRC regarding uranium

State	Location	Company	Site	Date	ADAMS NRC #
AL	Blount Co	Ft. McClellan	Blount Co, AL	25-Aug-04	ML042100101
AL	Calhoun Co	Ft. McClellan	Calhoun Co, AL	25-Aug-04	ML042100101
AL	Cherokee Co	Ft. McClellan	Cherokee Co, AL	25-Aug-04	ML042100101
AL	Etowah Co	Ft. McClellan	Etowah Co, AL	25-Aug-04	ML042100101
AL	Ft. McClellan	Ft. McClellan	Pelham Range Burial Mound	6-Jul-03	ML032380139
AL	Ft. McClellan	Ft. McClellan	Pelham Range Burial Mound	25-Aug-04	ML042100101
AL	Jefferson Co	Ft. McClellan	Jefferson Co, AL	25-Aug-04	ML042100101
AL	St. Clair Co	Ft. McClellan	St. Clair Co, AL	25-Aug-04	ML042100101
AL	Tuscaloosa Co	Ft. McClellan	Tuscaloosa Co, AL	25-Aug-04	ML042100101
AZ	Kykotsmovi	Hopi Tribe	Tuba City Landfill	8-Feb-08	ML080600175
AZ	Monument Valley	DOE	Uranium Processing Site	14-Apr-10	ML102500091
AZ	Monument Valley	DOE	Uranium Processing Site	20-Apr-10	ML102500091

State	Location	Company	Site	Date	ADAMS NRC #
CA	Eureka	Enercon Services, Inc	Humboldt Bay Power Plant	26-Feb-09	ML101400089
CA	San Clemente	Southern California Edison Company	San Onofre Nuclear Generating Station, Unit 1	19-Apr-07	ML071440275
CA	San Clemente	Southern California Edison Company	San Onofre Nuclear Generating Station, Unit 1	19-Apr-07	ML071440275
CA	San Diego	General Atomics	General Atomics San Diego Facility	9-Jun-05	ML052060106
CA	San Diego	General Atomics	General Atomics San Diego Facility	17-Mar-06	ML072220127
CA	San Diego	General Atomics	TRIGA Reactor	1-May-07	ML071210461
CA	San Diego	General Atomics	TRIGA Reactor, Bldg 21	20-Nov-06	ML063390088
CA	San Diego	General Atomics	TRIGA Reactor, Bldg 21	15-Dec-07	ML080170056
CA	Eureka	Pacific Gas and Electric Company	Humboldt Bay Power Plant Unit 3	24-Jul-09	ML11160A211
CO	Boulder	NIST	NIST Boulder Campus	2-Nov-09	ML0923080053
CO	Boulder	NIST	NIST Boulder Campus ï Building 1 Affected Rooms	29-Apr-09	ML091880935
CO	Durango	US Dept of Energy	UMTRA Site	28-Aug-03	ML032510955
CO	Naturita	Rare Metals Company	Inactive Uranium Mill Site	15-Mar-80	ML993070012
CO	Naturita	Rare Metals Company	Inactive Uranium Mill Site	15-Jul-81	ML993070180

State	Location	Company	Site	Date	ADAMS NRC #
CT	Haddam Neck	Connecticut Yankee Atomic Power Company	Connecticut Yankee Decommissioning Project	11-Nov-04	ML071870507
CT	New Haven	General Electric Corporation Environmental Programs	United Nuclear Corporation H-Tract Naval Products Facility	13-Apr-11	ML111370419
CT	New Haven	Naval Products	Former UNC Manufacturing Facility	29-Nov-07	ML073380138
CT	New Haven	United Naval Products	Naval Products Manufacturing Facility	1-Aug-11	ML112160391
CT	New Haven	United Nuclear Corporation Naval Product Division	UNC H-Tract Facility, for Naval Reactors	13-Feb-97	ML110120443
CT	New Haven	United Nuclear Corporation Naval Product Division	UNC Manufacturing Facility	15-Sep-10	ML110310943
CT	Windsor	ABB Inc	Clam Shell Pile	30-Sep-10	ML102730670
CT	Windsor	ABB Mactec	CE Winsor Site	15-Feb-10	ML100610088
CT	Winsor	ABB Inc	CE Windsor Site	15-Sep-07	ML072890351
DC	Washington	US Army	Forrest Glen Annex Storage Tanks	15-Apr-01	ML111730608
FL	Eglin Air Force Base	Eglin Air Force Base	Test Area C-74L	14-Jan-03	ML030420534
HI	Honolulu	US Army	Pohakuloa Training Area and Schofield Barracks	15-Apr-08	ML091170322
HI	Honolulu	US Army	Schofield Barracks	20-Dec-07	ML091100214
HI	Honolulu	US Army	Schofield Barracks	4-Apr-08	ML090900400
ID	Grand View	US Ecology Idaho, Inc. (USEI)	Commercial Hazardous Waste Landfill	24-Jul-09	ML092880180
ID	North Fork	DOE	Salmon River Uranium Mill Development Site	4-Aug-08	ML082180190
ID	North Fork	U.S. Atomic Energy Commission (AEC)	Salmon River Mill	28-May-08	ML082380180

State	Location	Company	Site	Date	ADAMS NRC #
IL	Chicago	Kerr-McGee		25-Apr-00	ML010800387
IL	Chicago	Veterans Administration	Jesse Brown VA Medical Center	27-Apr-05	ML051190353
IL	Metropolis	Honeywell Specialty Chemicals	Metropolis Works (MTW)	1-Oct-07	ML072690539
IL	Springfield	Andrews Engineering Inc.	Honeywell Ponds	7-Jan-10	ML103430303
IL	Zion	Exelon Generation Company, LLC	Zion Station	15-Sep-06	ML062760017
IN	Madison	US Army	Jefferson Proving Ground	25-May-05	ML051520319
IN	Madison	US Army	Jefferson Proving Ground	3-Oct-06	ML073100079
IN	Madison	US Army	Jefferson Proving Ground	2-Aug-07	ML072220218
IN	Madison	US Army	Jefferson Proving Ground	30-Apr-08	ML081280145
IN	Madison	US Army	Jefferson Proving Ground	27-Mar-09	ML090980542
IN	Madison	US Army	Jefferson Proving Ground	15-Aug-09	ML092300593
IN	Madison	US Army	Jefferson Proving Ground	1-Mar-10	ML100690375
IN	Madison	US Army	Jefferson Proving Ground	15-Apr-10	ML102500347
IN	Madison	US Army Material Command	Jefferson Proving Ground	23-Apr-03	ML032180696
IN	Metropolis	Honeywell International, Inc.	Metropolis UF6 plant	28-Jun-02	ML022030279
IN	New Haven	US Army	Defense National Stockpile Center	15-Jan-09	ML090630166
IN	New Haven Depot	Defense National Stockpile	Defense National Stockpile Center	27-Oct-06	ML082480626
KY	Paducah	DOE	Depleted Uranium Hexafluoride Facility	15-Jun-04	ML050180301

State	Location	Company	Site	Date	ADAMS NRC #
MA	Attleboro	Texas Instruments, Inc	Fabrication of enriched uranium foils (starting in 1952)	29-Mar-90	ML070800472
MA	Plainville	Engelhard Corporation	Engelhard Corporation Facility	31-Jul-96	ML062190137
MA	Watertown	General Services Administration	Former Manhattan District Site	29-Mar-90	ML070800472
MA	Watertown	General Services Administration	Former Watertown Arsenal	7-Feb-03	ML030450056
MA	Watertown	General Services Administration	Former Watertown Arsenal	28-Aug-03	ML032270336
MA	Watertown	GSA	Former Watertown Arsenal	13-Sep-02	ML023610571
MA	Watertown	US Army	Former Watertown Arsenal	15-Jul-00	ML003736357
MA	Watertown	Watertown GSA	Former Watertown Arsenal	14-Jun-01	ML011130110
MD	Aberdeen	US Army	Bldg 1103A Area	15-Sep-10	ML103280196
MD	Aberdeen Proving Ground	US Army	Bush River - 26th Street Disposal Site	12-May-97	ML083660076
MD	Aberdeen Proving Grounds	US Army	Bush River Rad Yard	15-Jan-07	ML071520147
MD	Aberdeen Proving Grounds	US Army	Depleted Uranium Study Area (DUSA) of the Transonic Range	24-Mar-00	ML050280354
MD	Aberdeen Proving Grounds	US Army	R-14 Range	1-Jan-06	ML073180601
MD	Curtis Bay	Defense Logistics Agency	Curtis Bay Depot	19-Dec-07	ML080230572
MD	Rockville	NRC	NRC Ruling	14-Feb-08	ML080630377
MI	Breckenridge	Unknown	Breckenridge Site	22-Nov-10	ML103330479
MI	Kawkawlin Township	S.C. Holdings	SCA Hartley & Hartley Landfill Site	30-Sep-94	ML033430565

State	Location	Company	Site	Date	ADAMS NRC #
MO	Festus	Westinghouse Electric Company	Hematite Facility	15-Sep-03	ML050960138
MO	Festus	Westinghouse Electric Company	Hematite Site	15-Jan-05	ML052860160
MO	Festus	Westinghouse Electric Company	Hematite Site	15-Apr-06	ML062430608
MO	Festus	Westinghouse Electric Company, LLC	Former Hematite Fuel Manufacturing Facility	26-Aug-09	ML092710648
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	31-Jul-03	ML102850223
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	18-Mar-09	ML090820620
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	8-Mar-10	ML100750149
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	8-May-10	ML101310384
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	14-May-10	ML101410359
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	7-Oct-10	ML102850223
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	28-Jan-11	ML110330366
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	5-May-11	ML111260624
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	21-Jun-11	ML111730489
MO	Festus	Westinghouse Electric Corporation	Hematite Decommissioning Project	5-Jul-11	ML111880290

State	Location	Company	Site	Date	ADAMS NRC #
MO	Hematite	ABB Combustion Engineering	Hematite Site	24-Feb-89	ML053640229
MO	Hematite	ABB Combustion Engineering	Hematite Site	3-Oct-95	ML053640203
MO	Hematite	ABB Combustion Engineering		27-Nov-95	ML053650203
MO	Hematite	ABB Combustion Engineering Nuclear Power, Inc.	Hematite Nuclear Fuel Manufacturing Facility	20-Oct-95	ML053640203
MO	Hematite	ABB Combustion Engineering Nuclear Power, Inc.	Hematite Nuclear Fuel Manufacturing Facility	24-Jan-96	ML052360158
MO	Hematite	ABB Combustion Engineering Nuclear Power, Inc.	Hematite Nuclear Fuel Manufacturing Facility	10-Sep-99	ML052360114
MO	Hematite	Combustion Engineering	Combustion Eng Site	25-Jun-90	ML052550382
MO	Hematite	Combustion Engineering	Limestone Piles	25-Sep-89	ML052510771
MO	Hematite	Westinghouse	Hematite Decommissioning Project	15-Jan-05	ML083260050
MO	Hematite	Westinghouse Electric Company	Hematite Former Fuel Cycle Facility	13-Aug-99	ML050380550
MO	Hematite	Westinghouse Electric Company	Hematite Former Fuel Cycle Facility	15-Sep-03	ML050400627
MO	Hematite	Westinghouse Electric Company	Hematite Former Fuel Cycle Facility	15-May-04	ML050390291
MO	Hematite	Westinghouse Electric Corporation	Hematite Decommissioning Project	4-Sep-03	ML093430811
MO	Hematite	Westinghouse Electric Corporation	Hematite Decommissioning Project	19-Dec-07	ML093430822
MO	Hematite	Westinghouse Electric Corporation	Hematite Decommissioning Project	2-Mar-09	ML090780017
MO	Hematite	Westinghouse Electric Corporation	Hematite Decommissioning Project	17-Jun-09	ML091800302
MO	Independence	Rock Island Arsenal	Lake City Army Ammunition Plant	22-Aug-10	ML102640334
MO	Independence	US Army	Lake City Army Ammunition Plant	27-Sep-00	ML010810089

State	Location	Company	Site	Date	ADAMS NRC #
MO	St. Lewis	Mallinckrodt Inc.	Columbium-Tantalum (C-T) Plant	15-May-03	ML032600898
MO	St. Lewis	Mallinckrodt Inc.	Columbium-Tantalum (C-T) Plant	15-May-03	ML032600945
NE	Crawford	Cameco Resources	Crow Butte Operation	9-Nov-08	ML090630411
NE	Crawford	Cameco Resources	Crow Butte Operation	19-Feb-10	ML100700508
NE	Crawford	Cameco Resources	Crow Butte Operation	1-Sep-10	ML102600500
NE	Crawford	Cameco Resources	Crow Butte Operation	24-Feb-11	ML110840124
NE	Crawford	Cameco Resources	Crow Butte Uranium Project	3-Mar-08	ML080710479
NE	Crawford	Crow Butte Resources	Three Crow Expansion Area	19-Dec-07	ML10220281
NE	Crawford	Crow Butte Resources	Three Crow Expansion Area	21-Jun-10	ML10220281
NE	Crawford	Crow Butte Resources, Inc	Crow Butte Facility	19-Sep-07	ML072890610
NE	Crawford	Crow Butte Resources, Inc	In situ leach uranium extraction facility	15-Jun-04	ML071760350
NE	Crawford	Crow Butte Resources, Inc	In situ leach uranium extraction facility	15-Mar-07	ML071760349
NE	Crawford	Crow Butte Resources, Inc	In situ leach uranium extraction facility	15-Mar-07	ML071870302
NE	Omaha	Veterans Administration	Omaha Veterans Medical Center, Alan J. Blotcky Reactor Facility	18-Dec-02	ML061380595
NJ	Fort Monmouth	US Army	U.S. Army Communications - Electronics Command AMSEL-SF-RER	13-May-98	ML063310284

State	Location	Company	Site	Date	ADAMS NRC #
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	16-Mar-99	ML023470315
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	1-Sep-99	ML023470315
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	8-Nov-01	ML021150357
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	18-Dec-02	ML023570327
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	15-Apr-03	ML060060003
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	26-Jun-03	ML031960118
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	15-Sep-03	ML060060003
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	1-Dec-03	ML040250070
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	11-Dec-03	ML040130730
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	15-Dec-04	ML060060003
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	20-Jan-05	ML050400019
NJ	Lakehurst	Heritage Minerals, Inc	Heritage Mineral Site	23-Dec-05	ML060060003
NJ	Manchester Township	Heritage Minerals, Inc	Heritage Mineral Site	30-Dec-05	ML060450447
NJ	Manchester Township	Heritage Minerals, Inc	Heritage Mineral Site	18-May-06	ML060750104
NJ	Maywood	Stepan Company	Complex Decommissioning Site	17-Nov-10	ML110750085
NJ	Maywood	Stepan Company	Maywood Chemical Works	23-Mar-10	ML102740079
NJ	Maywood	Stepan Company	Maywood Chemical Works	10-Nov-10	ML110840538

State	Location	Company	Site	Date	ADAMS NRC #
NJ	Newfield	15 Shieldalloy Metallurgical Corporation	Dl 11 and D102/112 Production Departments and Flex-Kleen Baghouse	24-Jun-03	ML031770069
NJ	Newfield	Shieldalloy Metallurgical Corp	Ferro-columbium smelting	29-Mar-90	ML070800472
NJ	Newfield	Shieldalloy Metallurgical Corp	Shieldalloy Metallurgical Corp	3-May-04	ML100120449
NJ	Newfield	Shieldalloy Metallurgical Corp	SMC Site	8-Dec-98	
NJ	Newfield	Shieldalloy Metallurgical Corporation	Newfield Facility	21-Oct-05	ML053190220
NJ	Newfield	Shieldalloy Metallurgical Corporation	Newfield Facility	21-Oct-05	ML053330384
NJ	Newfield	Shieldalloy Metallurgical Corporation	Shieldalloy Metallurgical Corporation	3-Dec-93	ML070250238
NJ	Newfield	Shieldalloy Metallurgical Corporation	Shieldalloy Metallurgical Corporation	21-May-97	ML070190667
NJ	Newfield	Shieldalloy Metallurgical Corporation	Shieldalloy Metallurgical Corporation	28-Jul-98	ML071520099
NJ	Newfield	Shieldalloy Metallurgical Corporation (SMC)	Storage Yard	6-Aug-08	ML092940258
NJ	Newfield	Shieldalloy Metallurgical Corporation (SMC)	Storage Yard	15-Aug-09	ML092940273
NJ	Picatinny Arsenal	US Army	Area 1222	30-Jan-06	ML090820710
NJ	Picatinny Arsenal	US Army	Bldg 611B	18-May-07	ML071620348
NM	Albuquerque	Kirtland Air Force Base	OT-10	6-Jan-03	ML030080421
NM	Albuquerque	Kirtland Air Force Base	OT-10	22-Mar-03	ML032050716
NM	Albuquerque	Kirtland Air Force Base	OT-10	13-Feb-04	ML041250063

State	Location	Company	Site	Date	ADAMS NRC #
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	15-Sep-86	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Apr-97	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	18-Apr-97	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Jun-97	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Jul-97	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	28-Jul-98	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Nov-98	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	14-Jun-99	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	10-Nov-99	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	5-Jun-00	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	22-Jun-00	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	22-Jul-00	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Aug-00	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	26-Apr-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-May-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	4-May-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	14-May-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	1-Jun-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	5-Jun-01	ML050400566

State	Location	Company	Site	Date	ADAMS NRC #
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	25-Jul-01	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	4-May-02	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	9-Nov-04	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Ambrosia Lake facility	19-Jan-05	ML050400566
NM	Ambrosia Lake	Rio Algom Mining LLC	Lined Evaporation Ponds	15-Oct-04	ML050240062
NM	Carlsbad	Environmental Evaluation Group	Waste Isolation Pilot Plant	30-Jan-90	ML031820560
NM	Lea County	International Isotopes Fluorine Products	Deconversion of Depleted Uranium	15-Jun-08	ML110540622
NM	McKinley County	Rio Algom Mining LLC	Ambrosia Lake facility	24-Sep-09	ML092990536
NY	Bayside	Sylvania-Corning Nuclear Corporation	Metallurgical Laboratory	1-Mar-80	ML021070380
NY	Buchanan	Enteray Nuclear Northeast	Indian Point Energy Center	31-Dec-10	ML11143A052
NY	Ithaca	Ward Center for Nuclear Studies (WCNS) at Cornell University	TRIGA Reactor	6-Jun-06	ML061030501
NY	West Valley	DOE	West Valley Demonstration Project	16-Sep-09	ML092730062
NY	West Valley	DOE	West Valley Demonstration Project	29-Sep-09	ML100040363
NY	West Valley	DOE	West Valley Demonstration Project	14-Oct-09	ML100040378
NY	West Valley	DOE	West Valley Demonstration Project	6-Nov-09	ML093220819
NY	West Valley	DOE	West Valley Demonstration Project	17-Dec-09	ML093560393
NY	West Valley	DOE	West Valley Demonstration Project	5-Feb-10	ML100491354
NY	West Valley	West Valley Environmental Services	West Valley Demonstration Project	15-Dec-08	ML083659350
NY	West Valley	West Valley Environmental Services	West Valley Demonstration Project	29-Dec-08	ML090771111

State	Location	Company	Site	Date	ADAMS NRC #
OH	Cambridge	Shieldalloy Metallurgical Corp	Columbium ore processing	29-Mar-90	ML070800472
OH	Cleveland	Chemetron Corp	Bert Ave (Road)	29-Mar-90	ML070800472
OH	Lima	BP Chemicals	Active Petrochemcial Plant	29-Mar-90	ML070800472
OH	Oxford	Alba Craft	Uranium metal machining, Alba Craft Site	18-Jun-02	ML040120774
OH	Piketon	American Centrifuge	American Centrifuge Plant	17-Feb-06	ML060590634
OH	Piketon	American Centrifuge	American Centrifuge Plant	15-Apr-06	ML061250101
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	22-Sep-95	ML11194A293
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	22-Sep-95	ML11194A293
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	9-May-11	ML11194A293
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	17-May-11	ML11194A293
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	31-May-11	ML11194A293
OH	Piketon	United States Enrichment Corporation	Portsmouth Facility	27-Jun-11	ML11194A293
OH	Piketon	USEC	American Centrifuge Plant	15-Aug-05	ML052440433
OH	Portsmouth	Louisiana Energy Services, LP	DU F6 conversion facility	15-Jun-04	ML051030392
OH	Sandusky	NASA	Plum Brook Reactor Facility	15-May-06	ML061390297
OH	Sandusky	NASA	Plum Brook Reactor Facility	15-Feb-07	ML070450170
OH	West Jefferson	Battelle	JN-2, Critical Assembly Laboratory	17-Nov-04	ML043280388

State	Location	Company	Site	Date	ADAMS NRC #
OK	Crescent	Cimarron Corp	Cimarron Site	15-Dec-06	ML063470609
OK	Crescent	Cimarron Corporation	Cimarron Facility	1-Aug-86	ML090120773
OK	Crescent	Cimarron Corporation	Cimarron Facility	14-Jan-98	ML090120770
OK	Crescent	Cimarron Corporation	Cimarron Facility	12-Mar-98	ML090120773
OK	Crescent	Kerr-McGee	Inactive Pu and U fuel fabrication plants (closed in 1975)	29-Mar-90	ML070800472
OK	Crescent	Kerr-McGee	Kerr-McGee Fuel Fabrication Plant, Cimarron Plant	29-Mar-90	ML070800472
OK	Crescent	Kerr-McGee Corporation	Cimarron Facility	13-Jul-95	ML090090366
OK	Crescent	Kerr-McGee Corporation	Cimarron Facility	15-Jul-95	ML090060780
OK	Crescent	Kerr-McGee Corporation	Sequoyah Fuels Cimarron Plant	18-Oct-06	ML063120296
OK	Crescent	Tronox	Cimarron Site	15-Oct-06	ML063120293
OK	Crescent	Cimarron Corporation	Cimarron Site	15-Aug-05	ML052270488
OK	Crushing	Kerr-McGee	Inactive Th and U fuel fabrication plants (closed in 1966)	29-Mar-90	ML070800472
OK	Cushing	Kerr-McGee Corporation	Cushing Refinery Site	28-Apr-95	ML060040090
OK	Cushing	Kerr-McGee Corporation	Kerr-McGee Cushing Refinery Decommissioning Site	18-Feb-05	ML050550111
OK	Cushing	Kerr-McGee Corporation	Kerr-McGee Cushing Refinery Decommissioning Site	18-Feb-05	ML050560319
OK	Cushing	Kerr-McGee Corporation	Kerr-McGee Cushing Refinery Decommissioning Site	18-Feb-05	ML050690365
OK	Cushing	Kerr-McGee Corporation	Kerr-McGee Cushing Refinery Decommissioning Site	28-Apr-05	ML051240394

State	Location	Company	Site	Date	ADAMS NRC #
OK	Gore	General Atomics	Sequoyah Facility	2-Jul-09	ML092040088
OK	Gore	Sequoyah Fuels	Sequoyah Facility, CaFl burial site	31-Jan-06	ML060370532
OK	Gore	Sequoyah Fuels Corp	Uranium conversion site	15-May-08	ML081300103
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	18-Jan-91	ML061590228
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	20-Jan-03	ML030450446
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	8-Aug-03	ML032400449
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	31-May-05	ML051810525
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	31-May-05	ML052010654
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Corporation Site	12-Jan-10	ML100120264
OK	Gore	Sequoyah Fuels Corporation	Uranium Conversion Operation	18-Aug-10	ML102380151
OK	Gore	Sequoyah Fuels Corporation	Sequoyah Fuels Uranium Conversion Facility	4-Nov-10	ML103550604
OK	Muskogee	Fansteel Inc	FMRI rare earth recovery facility	5-Nov-99	ML993610124
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	23-Dec-99	ML993610124
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	25-Apr-00	ML010800387
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	30-May-01	ML011130110
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	15-Nov-02	ML023510034

State	Location	Company	Site	Date	ADAMS NRC #
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	18-Apr-03	ML030920733
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	23-Sep-04	ML043170305
OK	Muskogee	Fansteel Inc	Rare Earth Recovery Facility	4-Nov-05	ML053390056
OK	Muskogee	Fansteel Inc	FMRI rare earth recovery facility	12-Apr-06	ML061250477
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	25-Sep-00	ML010460325
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	6-Nov-00	ML010460325
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	21-Nov-00	ML011520269
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	4-Dec-00	ML010460325
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	15-Jan-01	ML010460325
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	16-Jan-01	ML010460325
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	6-Feb-01	ML011520269
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	30-Mar-01	ML011520269
OK	Oklahoma City	Cimarron Corporation	Kerr-McGee Technical Center	9-May-11	ML011520269
OK	Oklahoma City	Kerr-McGee Corporation	Kerr-McGee Technical Center	7-Aug-02	ML023500440

State	Location	Company	Site	Date	ADAMS NRC #
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	7-Feb-05	ML050600446
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	10-Feb-05	ML050870612
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	3-Mar-05	ML050980104
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	3-Mar-05	ML051170388
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	22-Jul-05	ML052100045
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	25-Aug-05	ML052870510
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	1-Nov-05	ML053460484
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	22-Dec-05	ML060460613
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	17-Feb-06	ML060930699
OK	Tulsa	Kaiser Aluminum and Chemical Corporation	Kaiser Aluminum Specialty Products	8-Jun-06	ML061800480
PA	Apollo	B&W Labs	Active radioanlaytical lab	29-Mar-90	ML070800472
PA	Apollo	Babcock & Wilcox	Apollo Site	17-Jan-97	ML992920098
PA	Apollo	Babcock & Wilcox	Apollo Site	17-Jan-97	ML993360246
PA	Boyertown	Cabot Corporation	County Line Road, Building 73	5-Sep-01	ML012970344
PA	Boyertown	Cabot Performance Materials	Reading Facility	23-Dec-99	ML993630456
PA	Boyertown	Cabot Supermetals, Inc	Cabot Supermetals Facility	4-Oct-02	ML031820456
PA	Boyertown	Cabot Supermetals, Inc	Cabot Supermetals Facility	17-Apr-03	ML031690541
PA	Boyertown	Cabot Supermetals, Inc	Cabot Supermetals Facility	11-Dec-03	ML040610495
PA	Boyertown	Cabot Supermetals, Inc	Cabot Supermetals Facility	21-Apr-04	ML041480270

State	Location	Company	Site	Date	ADAMS NRC #
PA	Carnegie	Superior Steel & Metals Corporation	Uranium metal strip and plate fabrication site	30-Sep-85	ML031050089
PA	Carnegie	Superior Steel & Metals Corporation		18-Nov-03	ML040350619
PA	Leechburg	Kiski Valley Water Pollution Control Authority	Babcock & Wilcox (B&W) Apollo facility	27-Feb-04	ML041600337
PA	Leechburg	Kiski Valley Water Pollution Control Authority	Babcock & Wilcox (B&W) Apollo facility	22-Jun-04	ML041110312
PA	Parks Township	US Army	SLDA FUSRAP Site Remediation	15-May-09	ML091950603
PA	Reading	Cabot Performance Materials		25-Apr-00	ML010800387
PA	Reading	Cabot Performance Materials		18-Jun-01	ML011130110
PA	Springdale	Manhattan Engineering District	C.H. Schnoor Site	18-Jun-02	ML040120774
PA	Vandergrift	Kiski Valley Water Pollution Control Authority		25-Apr-00	ML010800387
PA	Vandergrift	Kiski Valley Water Pollution Control Authority		29-May-01	ML011130110
PA	Vandergrift	Kiski Valley Water Pollution Control Authority		31-Dec-03	ML032250442
PA	Washington	Chevron Mining	Washington Remediation Project	15-Nov-07	ML073380039
PA	Washington	Molybdenum Corporation of America	Washington Facility	26-Sep-02	ML030080218
PA	York	Molycorp Inc		25-Apr-00	ML010800387
SC	Aiken	DOE	Savannah River Operations	15-May-95	ML071310331
SC	Aiken	Washington Savannah River Company	Savannah River Site	15-Mar-06	ML073240767
SC	Columbia	Westinghouse	Westinghouse Columbia Plant	29-Jan-01	ML062090568
SC	Columbia	Westinghouse Electric Company	Columbia Nuclear Fuel Plant	16-Feb-01	ML010920231

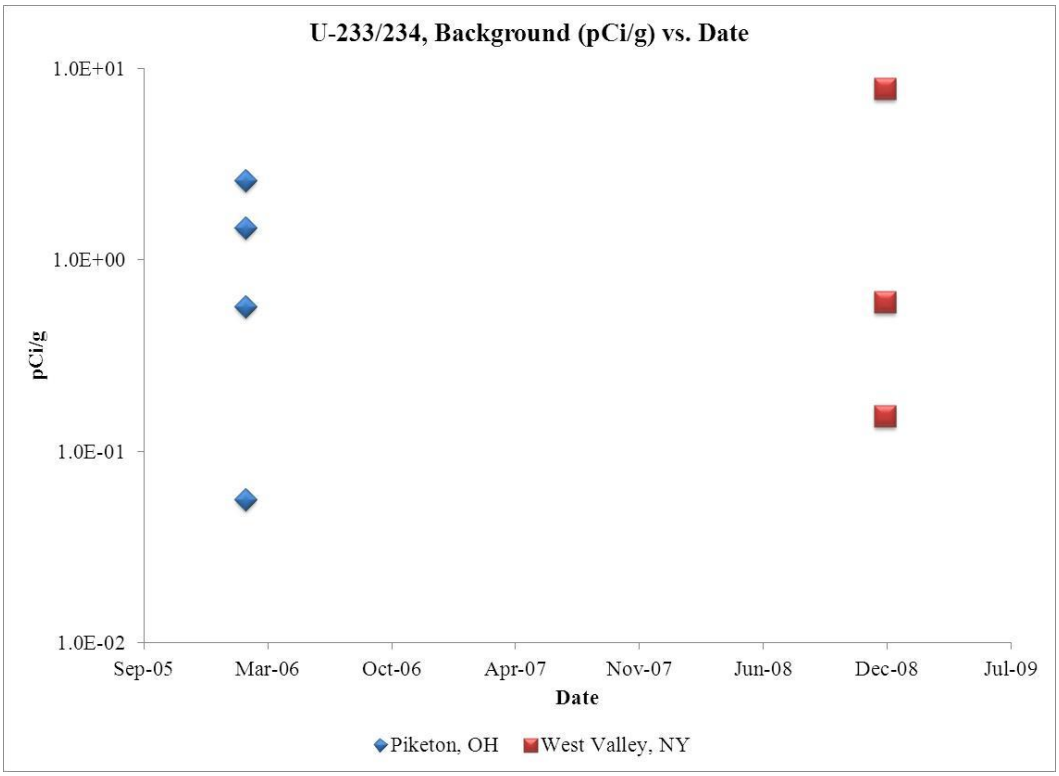
State	Location	Company	Site	Date	ADAMS NRC #
SD	Dewey-Burdock	Powertech(USA) Inc	Dewey-Burdock Uranium In-situ Recovery Facility	8-Oct-07	ML092870413
SD	Dewey-Burdock	Powertech(USA) Inc	Dewey-Burdock Uranium In-situ Recovery Facility	30-Sep-08	ML092870413
SD	Dewey-Burdock	Powertech(USA) Inc	Dewey-Burdock Uranium In-situ Recovery Facility	1-Oct-08	ML091070696
SD	Dewey-Burdock	Powertech(USA) Inc	Dewey-Burdock Uranium In-situ Recovery Facility	29-Jan-09	ML092870413
SD	Edgemont	Tennessee Valley Authority	Pine Hills Mill Area	5-Feb-88	ML11167A052
SD	Fall River and Custer Counties	Powertech (USA) Inc.	Dewey-Burdock Project	28-Aug-08	ML110050472
SD	Fall River and Custer Counties	Powertech (USA) Inc.	Dewey-Burdock Project	23-Oct-08	ML110050472
TN	Erwin	Nuclear Fuel Services, Inc	BLEU Project	24-Oct-86	ML110070201
TN	Erwin	Nuclear Fuel Services, Inc	Nuclear Fuel Services North Site	15-Feb-08	ML080840391
TN	Lawrenceburg	UCAR Carbon Company	Highway 43 South	16-Feb-05	ML060340068
UT	Clive	Envirocare of Utah	Waste Site	20-Jan-98	ML993550254
UT	Cresent Junction	DOE	Moab Title I Uranium Mill Tailings	3-Mar-08	ML080920250
UT	Green River	MK-Ferguson	Inactive Uranium Mill Tailings Site	1-Apr-90	ML040350760
UT	Skull Valley	Private Fuel Storage, LLC	Reservation of the Skull Valley Band of Goshute Indians	31-Dec-01	ML020150217
UT	White Mesa	International Uranium (USA) Corporation	White Mesa Mill	5-Feb-02	ML030450294
VA	Charlottesville	University of Virginia	University of Virginia Reactor (UVAR)	2-Nov-00	ML010050135
VT	Vernon	Entergy Nuclear Operations, Inc.	Vermont Yankee Nuclear Power Station	9-May-11	ML11132A135

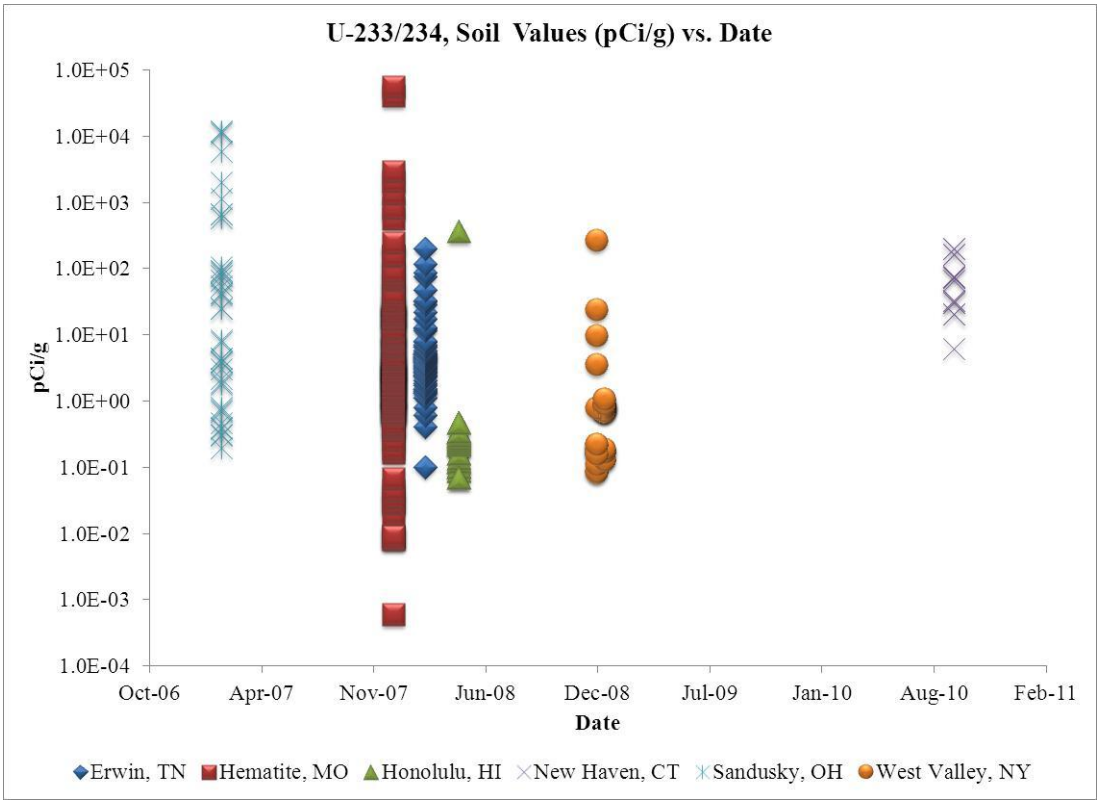
State	Location	Company	Site	Date	ADAMS NRC #
WY	Riverton	Pathfinder Mines Corporation (PMC)	Lucky Mc Mill Site	16-Feb-99	ML081930316
WY	Riverton	United States Department of Energy	Riverton Uranium Mill Tailings Remediation (UMTRA) Site	15-Sep-03	ML033160345
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	10-Sep-93	ML081540395
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	28-Sep-93	ML081540395
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	30-Oct-93	ML081540395
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	24-May-95	ML081540395
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	8-Jun-95	ML081540395
WY	Riverton	US Energy Corp	Green Mountain Ion Exchange	20-Dec-99	ML081540395
WY	Sweetwater County	Lost Creek ISR, LLC	Lost Creek Project	5-Aug-09	ML092310728
WY	Sweetwater County	Rio Tinto Energy America, Inc.	UMETCO Gas Hills Site	7-Oct-08	ML082820367
WY	Sweetwater County	Uranium One	Antelope and JAB Uranium Project	15-Jun-08	ML082730490
WY	Sweetwater County	Ur-Energy USA Inc.	Lost Creek ISR Uranium Project	14-Nov-06	ML07321169
WY	Campbell	Uranium One	Moore Ranch In Situ Uranium Recovery Project	11-Jul-08	ML082060527

Some documents from the NRC applied nationwide and had no state or location.

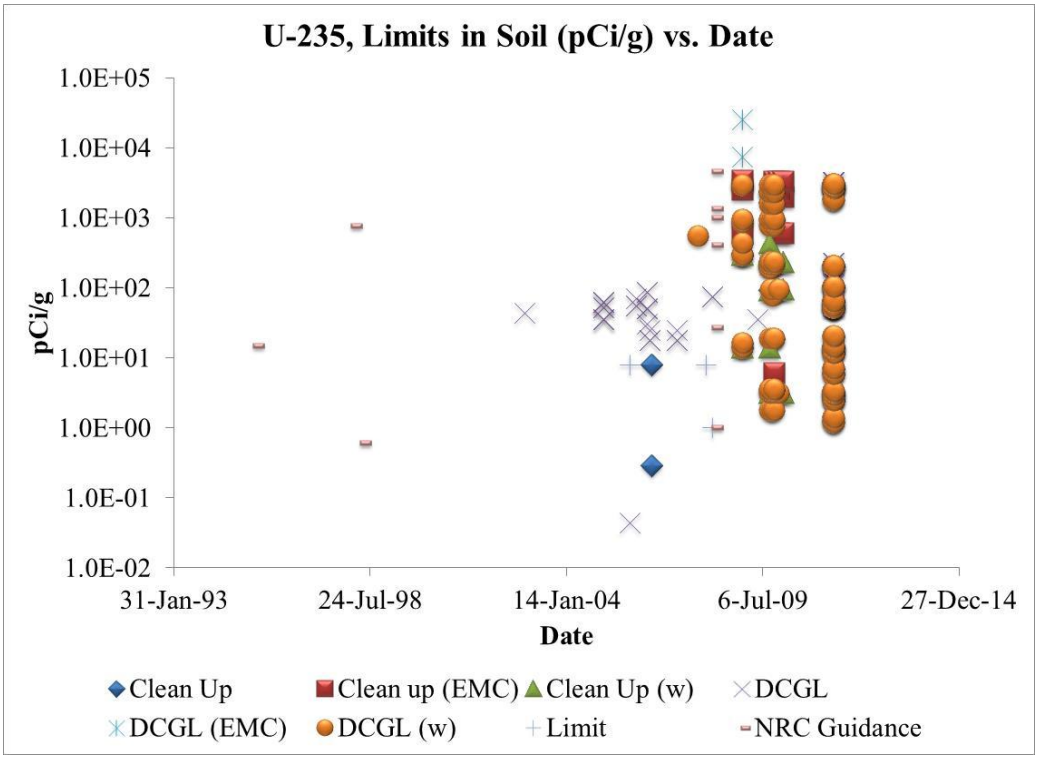
Agency	Site	Date	ADAMS NRC #
DOE	Office of Fissile Materials Disposition	15-Jun-96	ML101590138
EPA	USA	15-Mar-89	ML031770293
EPA	USA	3-Aug-99	ML022830208
NRC	In Situ (ISL) recommendations	12-Mar-99	ML072780259
NRC	NRC Ruling	29-Mar-02	ML020910599
NRC	NRC Ruling	11-Apr-02	ML021480325
NRC	NUREG-1496	1-Jul-97	ML042330385
NRC	NUREG-1717, ñSystematic Radiological Assessment of Exemptions for Source and Byproduct Materials.ò	UNKNOWN	ML030920597
NRC	Uranium Mills and In Situ Sites	15-Apr-98	ML992910059
NRC	Uranium recovery facilities	10-Feb-99	ML992800103

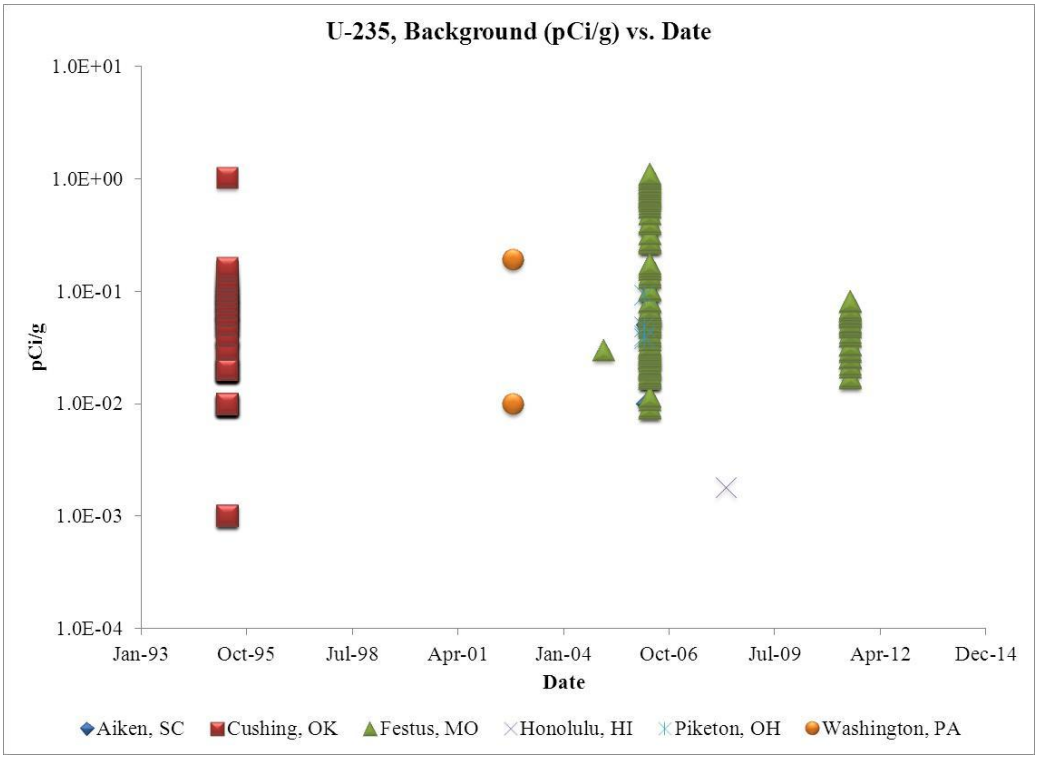
Appendix B: U-233/234 Background and Soil Sample Values

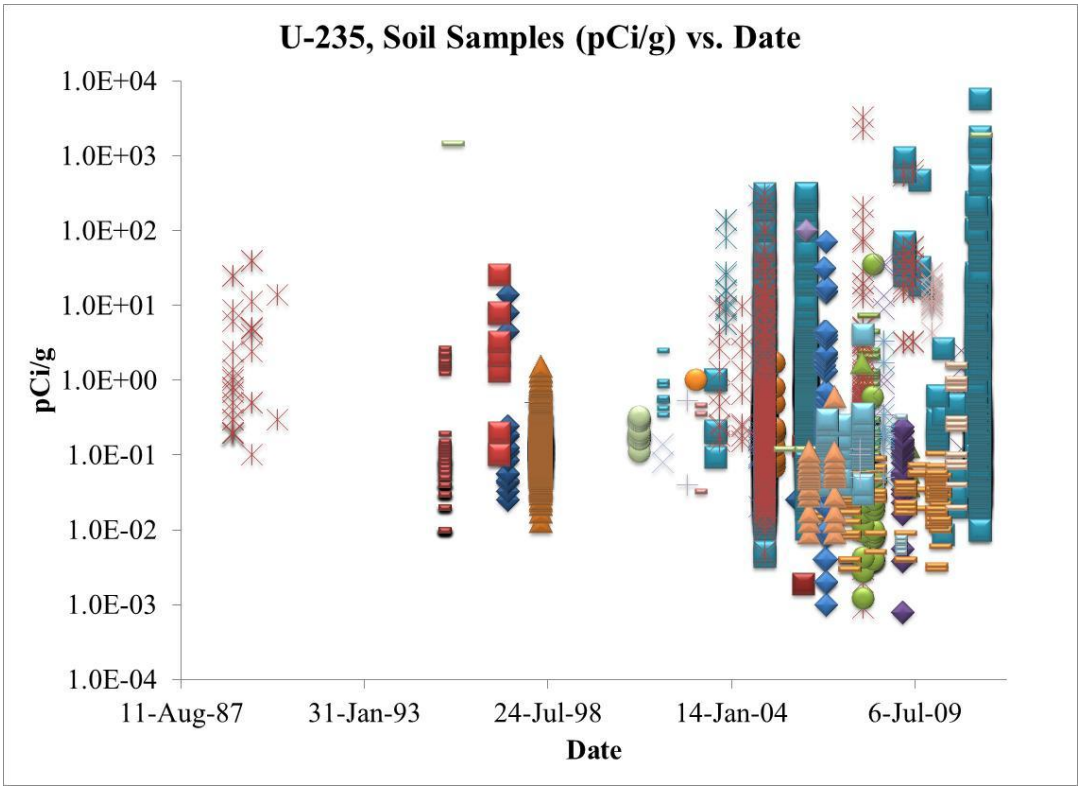




Appendix C: U-235 Limits, Background and Soil Sample Values






U-235, Soil Samples (pCi/g) vs. Date
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
pCi/g
11-Aug-87
31-Jan-93
24-Jul-98
14-Jan-04
6-Jul-09
Date


Aberdeen Proving Ground, MD
Aiken, SC
Boulder, CO
Breckenridge, MI
Carnegie, PA
Chicago, IL
Crescent, OK
Cushing, OK
Erwin, TN
Eureka, CA
Festus, MO
Fort Monmouth, NJ
Haddam Neck, CT
Hematite, MO
Honolulu, HI
Kykotsmovi, AZ
Lakehurst, NJ
Madison, IN
New Haven Depot, IN
New Haven, CT
Newell, WV
Newfield, NJ
North Fork, ID
Omaha, NE
North Fork, ID
Omaha, NE
Piketon, OH
Richland, WA
San Diego, CA
Sandusky, OH
Skull Valley, UT
Springfield, IL
Washington, DC
Washington, PA
West Valley, NY
Windsor, CT

Appendix D: U-236 Background, MDA and Soil Sample Values