Evaluation of Long-Term Risks Associated with Landfill Disposal of Uranium Hexafluoride Samples

Prepared for

Westinghouse Electric Company, LLC
Columbia Fuel Fabrication Facility
Columbia, SC

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Tetra Tech NUS, Incorporated
20251 Century Boulevard, Suite 200
Germantown, Maryland 20874-7114

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Prepared by: Bart W. Bartram

Bart W. Bartram, Physicist

Approved by:

Mic Griben
Operations Manager, Germantown Office

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ACRONYMS AND ABBREVIATIONS

ac	acre
atm	atmosphere
ADU	ammonium diuranate
AIHA	American Industrial Hygiene Association
ALARA	as low as reasonably achievable
ANL	Argonne National Laboratory
Bq	Becquerel
^{o}C	degrees Celsius
CEDE	committed effective dose equivalent
CFFF	Columbia Fuel Fabrication Facility
CFR	Code of Federal Regulations
Ci	curie
cm	centimeter
cm^3	cubic centimeter
DCF	dose conversion factor
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ERPG	emergency response planning guidelines
ºF	degrees Fahrenheit
ft	feet
ft^3	cubic feet
g	gram
gal	gallon (U.S.)
ha	hectare
HF	hydrogen fluoride
hr	hour
in.	inch
kg	kilogram
km	kilometer
L	liter
LLC	Limited Liability Company
LMOP	Landfill Outreach Program
μCi	microcurie
μg	microgram
m	meter
m^2	square meters
mg/m^3	milligrams per cubic meter

ACRONYMS AND ABBREVIATIONS (Cont'd)

mi	statute mile(s)
mil	milliliter
mPa	megapascal
mrem	millirem
Pa	pascal
pCi	picocurie
psi	pounds per square inch
NRC	U.S. Nuclear Regulatory Commission
s	second
SC	South Carolina
SC-DHEC	South Carolina Department of Health and Environmental Control
SiO_2	silicon dioxide
SNM	special nuclear material
SWAIP	Special Waste Acceptance and Implementation Plan
TtNUS	Tetra Tech NUS, Incorporated
^{235}U	uranium-235
UF_6	uranium hexafluoride
UO_2	uranium dioxide
UO_2F_2	uranyl fluoride
WEC	Westinghouse Electric Company, LLC
WMI	Waste Management, Incorporated
yr	year

UNITS CONVERSION FACTORS

Length

1 centimeter (cm) = 0.3937 inch	1 inch = 2.54 cm
1 centimeter = 0.03281 foot (ft)	1 foot = 30.48 cm
1 meter (m) = 3.281 feet	1 ft = 0.3048 m
1 meter = 0.0006214 mile (mi)	1 mi = 1609 km
1 kilometer (km) = 0.6214 mile	1 mi = 1.609 km

Area

1 square centimeter (cm^2) = 0.1550 square inch (in^2)	1 in^2 = 6.452 cm^2
1 square meter (m^2) = 10.76 square feet (ft^2)	1 ft^2 = 0.09294 m^2
1 square kilometer (km^2) = 0.3861 square mile (mi^2)	1 mi^2 = 2.590 km^2
1 hectare (ha) = 2.4710 acres (ac)	1 ac = 0.4047 ha
	1 ac = 43560 ft^2
1 hectare (ha) = 10,000 square meters (m^2)	1 ft^2 = 0.00002296 ac

Volume

1 cubic centimeter (cm^3) = 0.0610 cubic inch (in^3)	1 in^3 = 16.39 cm^3
1 cubic meter (m^3) = 35.31 cubic feet (ft^3)	1 ft^3 = 0.02832 m^3
1 cubic meter (m^3) = 1.308 cubic yards (yd^3)	1 yd^3 = 0.7646 m^3
1 liter (L) = 1.057 quarts (qt)	1 qt = 0.9463 L
1 liter = 0.2642 gallon (gal)	1 gal = 3.785 L

Mass

1 kilogram (kg) = 2.205 pounds (lb)	1 lb = 0.4536 kg
1 metric ton (mt) = 1.102 tons	1 ton = 0.9072 mt

Pressure

1 pascal (Pa) = 1 newton/m^2	1 atm = 0.101 MPa
1 pascal = 1.451×10^{-4} lb/in^2 (psi)	1 atm = 14.8 psi

Radiation

1 becquerel (Bq) = 1 disintegration /s	
1 becquerel = 2.703×10^{-11} curies (Ci)	1 Ci = 3.70×10^{10} Bq
1 sievert (Sv) = 100 rem	1 rem = 0.01 Sv

1.0 INTRODUCTION

The Westinghouse Electric Company, LLC (WEC) operates the Columbia Fuel Fabrication Facility (CFFF) to fabricate low-enriched uranium fuel assemblies for commercial light-water nuclear reactors. The CFFF is approximetly 13 km (8 mi) southeast of Columbia, SC in Richland County. The facility has been in operation from 1969 to the present. The fabrication process involves the chemical conversion of uranium hexafluoride (UF_6) to uranium dioxide (UO_2) using the Ammonium Diuranante (ADU) Process. The uranium dioxide is formed into ceramic fuel pellets which are used in the nuclear fuel assembly. In accordance with Title 10, Code of Federal Regulations, Part 70 (10 CFR 70), WEC operates CFFF under Special Nuclear Material License 1107 (SNM-1107) issued by the U.S. Nuclear Regulatory Commission (NRC).

As part of CFFF operations, samples of UF_6 contained in P-10 sample tubes are analyzed for uranium isotopic content. During preparation of receipt transaction documentation on February 12, 2008, WEC personnel discovered that laboratory analysis results for two shipping containers, each with eight, P-10 sample tubes could not be located. Investigating further, the sample tubes and shipping containers could not be located in the laboratory or on site. WEC postulates that the two shipping containers were inadvertently sent to the Richland County Landfill operated by Waste Management, Incorporated (WMI) in Elgin, SC. There is no physical evidence to substantiate that this material was actually disposed of at the facility. Historically, WMI procedures have resulted in the identification and removal of unacceptable wastes in accordance with the facility's Special Waste Acceptance and Implementation Plan (SWAIP).

The two shipping containers consist of 25.9 L (6.85-gal) galvanized buckets, painted blue with a rim-sealed top. The P-10 sample tubes are fabricated from flurothene and are sealed with monel fittings. Within each bucket, the eight, P-10 sample tubes are packed in polystyrene "peanuts". There is approximately 100 grams (g) of UF_6 containing 64 g uranium at an average enrichment of 4.95 percent uranium-235 (^{235}U) in each of the two shipping containers. The 100 g of UF_6 is evenly distributed in the eight P-10 sample tubes in the bucket. The total uranium amount of 128 g has a radioactivity content of 409.4 microcuries (μCi).

WEC notified the NRC of the event on the day it was discovered, and NRC included the event in the Current Event Notification Report for February 15, 2008 (NRC 2008). WEC also discussed the matter with the South Carolina Department of Health and Environmental Control (SC-DHEC) and Richland County. The initial WEC assessment of the event indicated that 1) the potential radiological and chemical hazards posed by the potential improper disposal of the material at the Richland County Landfill are low, and 2) risk to involved personnel, should a retrieval operation be conducted, would outweigh the risk of leaving the material in the landfill location. During discussions with WEC, SC-DHEC indicated that it would be necessary for WEC to document the long term viability of leaving the material in the landfill location. WEC conveyed this information to WMI on February 18, 2008.

Subsequently, WEC asked Tetra Tech NUS, Incorporated (TtNUS) to perform an independent assessment of the potential risks associated with the long term disposal of the UF_6 samples at the landfill location. This report documents the TtNUS risk assessment. Section 2.0 presents a summary of the assessment, with details of the study presented in subsequent sections. Section 3.0 presents additional background information to provide a basis for the assessment. Section 4.0 describes the assessment methodology. Section 5.0 presents the results and conclusions of the study. Section 6.0 presents a list of cited references.

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2.0 SUMMARY

The potential hazards associated with the UF_6 sample tubes were assessed through several approaches, including:

- Evaluate maximum exposure scenarios in which the material was released at ground level to evaluate downwind radiation doses and concentrations of hazardous compounds.
- Apply the U.S. Department of Energy (DOE) model, RESRAD 6.4, for evaluation of long-term potential risks associated with land disposal of radioactive materials.

The results using each of these approaches is summarized below:

2.1 Maximum Exposure Scenario

The U.S. Environmental Protection Agency's (EPA) CAP-88 model was used in evaluating the maximum exposure scenario. In this approach, all the radioactivity in the UF_6 samples of 409.4 μCi is assumed to be released at ground level under restrictive meteorological conditions that lead to the highest concentrations. The results indicated that the radiation dose associated with the maximum exposure scenario is 5.5 millirem [mrem]/yr at 100 m and 0.96 mrem/yr at 250 m. This can be compared to background radiation levels of nominally 300 mrem/yr and the EPA annual dose criterion of 100 mrem/yr to members of the public from all human-related sources.

The estimated maximum exposure over a period of 1 hour to UF_6 is 0.32 mg/m^3 at 100 m and 0.055 mg/m^3 at 250 m. Assuming the concentrations occurred only during a plume passage time of 100 s, the estimated concentrations would be 11.6 mg/m^3 at 100 m and 2.0 mg/m^3 at 250 m.

The American Industrial Hygiene Association (AIHA) has developed emergency response planning guidelines (ERPGs) for acute exposures at three different levels of severity. These guidelines represent concentrations for exposure of the general population for up to 1 hour associated with effects expected to be mild or transient (ERPG-1), irreversible or serious (ERPG-2), and potentially life-threatening (ERPG-3). ERPG values for UF_6 are as follows:

- ERPG-1: 5.0 mg/m^3
- ERPG-2: 15.0 mg/m^3
- ERPG-3: 30.0 mg/m^3

The results indicate that the concentrations would be below the ERPG-1 values at 100 m for a 1-hr reference exposure period. The concentrations during a 100 s plume passage period would be below the ERPG-2 value at 100 m.

As an extension of the maximum exposure scenario, the potential for direct contact with the UF_6 has been considered. This could potentially occur, for example, at sometime in the future should excavation occur at the landfill. The material is corrosive, and harmful by inhalation, ingestion or skin absorption. The effects of exposure may be delayed. Should a worker come into direct contact with the UF_6 sample tubes, and be subject to a skin exposure, there is potential for an acid burn, which is treatable with calcium gluconate.

2.2 RESRAD Modeling

RESRAD Modeling: In applying RESRAD to the UF_6 samples, the radioactive inventory of 409.4 μCi is assumed to be initially uniformly distributed in 1.5 m^3 of loose sand. Then, three scenarios were considered:

- Scenario 1: A future excavation scenario in which the contaminated soil ended up on the surface with an area of 10 m^2 and a depth of 0.15 m (i.e., 0.15 m x 10 m^2 = 1.5 m^3)
- Scenario 2: An in-place disposal scenario in which the material remained at a 6.1 m (20 ft) depth but distributed in the prior areal configuration
- Scenario 3: Radon from natural uranium in the soil. Doses are calculated resulting from radon associated with 1 picocurie (pCi)/g of natural uranium and its radioactive daughters emanating from a volume of soil with the same areal extent of 10 m^2 and a depth of 6.1 m (20 ft).

The RESRAD results indicate maximum annual doses of 4.1 mrem/yr for Scenario 1, 0.018 mrem/yr for Scenario 2, and 44 mrem/yr for Scenario 3. Based on these results, the doses due to natural uranium and its radioactive daughters, giving rise to radon exposures would be higher than doses due to the UF_6 exposure scenarios.

In reviewing the RESRAD output for the three scenarios, Scenario 1 is dominated by non-water pathways (primarily external exposure to ground contamination and inhalation), Scenario 2 is dominated by groundwater pathways, and Scenario 3 is dominated by natural radon. Both Scenarios 1 and 2 account for buildup of radon from the decaying initial uranium radionuclides. TtNUS has provided the RESRAD input files and the Summary Reports for each scenario. Those files provide detailed information on contributions by radionuclide and exposure pathway.

2.3 Conclusions

If it was determined that the UF_6 sample tubes were improperly disposed of in the Richland County Landfill the potential radiation and chemical exposure risks posed by the UF_6 sample tubes are small when compared to exposure guidelines and natural background radiation levels.

3.0 BACKGROUND INFORMATION

This section presents background information on the physical and chemical properties of uranium hexafluoride (UF_6) (Section 3.1); protection guidelines for radiation and hazardous material exposures (Section 3.2); the UF_6 shipping containers and P-10 sample tubes (Section 3.3); the landfill (Section 3.4); and the potential long-term fate of UF_6 in a landfill disposal condition (Section 3.5).

3.1 Uranium Hexafluoride

Information on UF_6 is summarized below with respect to its physical and chemical properties, and potential health effects associated with radiation and chemical exposure (based in part on ANL 2008).

3.1.1 Physical Properties

The mass density of solid UF_6 at 20°C (68°F) is 5.1 g/cm^3 and its molecular weight is 352 g/mole. At ambient conditions UF_6 is a volatile, white, crystalline solid. Solid UF_6 is readily transformed into the gaseous or liquid states by the application of heat. The phase diagram covering the range of conditions usually encountered in working with UF_6 is presented in Figure 3-1. It shows the correlation of pressure and temperature with the physical state of UF_6. The vapor pressure above the solid reaches 0.1 mPa (1 atm) at 56°C (133°F), the sublimation temperature. The triple point occurs at a pressure of 0.15 mPa (1.5 atm) and a temperature of 64°C (147°F). These are the only conditions at which all three states (solid, liquid and gas) can exist in equilibrium. If the temperature or pressure is greater than at the triple point, there will only be gas or liquid. Only the gaseous phase exists above 230°C (446°F), the critical temperature, at which the critical pressure is 4.61 mPa (45.5 atm). The vapor pressure above the solid reaches 0.1 mPa (1 atm) at 56°C (133°F), the sublimation temperature.

3.1.2 Chemical Properties

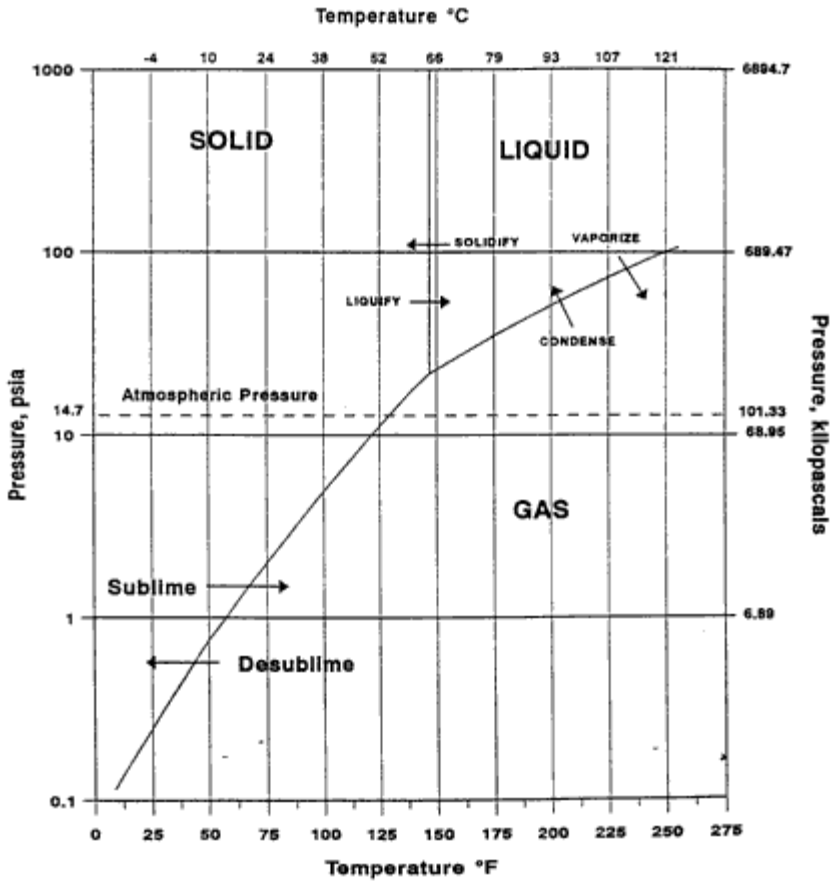
Uranium hexafluoride (UF_6) does not react with oxygen, nitrogen, carbon dioxide, or dry air. UF_6 is hygroscopic (i.e., moisture-retaining) and, in contact with water (H_2O), will decompose immediately into the soluble reaction products of uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF), both of which are water soluble. UF_6 is essentially inert to clean aluminum, steel, Monel, nickel, aluminum, bronze, copper, and Teflon.

When released to the atmosphere, gaseous UF_6 combines with humidity to form particulate UO_2F_2 and HF fumes. The reaction is fast and is dependent on the availability of water vapor.

In a fire, the reaction of UF_6 with water is accelerated because of the increased UF_6 vapor pressure and the water vapor formed in combustion of organic materials or hydrocarbons. Reaction of liquid UF_6 with hydrocarbon vapors is vigorous in flames, with formation of UF_4 and low-molecular-weight fluorinated compounds. More heat is generally released in these hydrocarbon interactions with UF_6 than in the corresponding reactions of hydrocarbons with oxygen.

3.1.3 Health Hazards

Uranium hexafluoride (UF_6) and related compounds have radiological and chemical characteristics that pose potential health risks. The uranium content is radioactive, with a



Source: ANL 2008

Figure 3-1 Phase Diagram for UF_6.

specific activity dependent on the percent enrichment of uranium-235 (^{235}U), exposure to which could result in a radiation dose. If UF_6 is released to the atmosphere, the UO_2F_2 and HF formed by reaction with moisture in the air can be chemically toxic. Uranium is a heavy metal that, in addition to being radioactive, can have toxic chemical effects (primarily on the kidneys) if it enters the bloodstream by means of ingestion or inhalation. HF is a corrosive gas that can damage the lungs if inhaled at high enough concentrations.

3.2 Protection Guidelines for Radiation and Hazardous Material Exposures

Exposure to ionizing radiation is characterized in terms of radiation dose, reported in units of millirem (mrem) in this report. The U.S. Environmental Protection Agency (EPA) has established radiation protection guidelines for members of the public such that radiation doses from all sources should be below 100 mrem/yr. For sites contaminated with radioactive materials that result in radiation doses greater than 100 mrem/yr, site cleanup criterion call for cleanup to as low as reasonable achievable (ALARA). In application of this criterion, the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) take this ALARA level to be 25 mrem/yr above background radiation levels.

When exposure to UF_6 is considered from a chemical toxicity viewpoint, the American Industrial Hygiene Association (AIHA) has developed emergency response planning guidelines (ERPGs) for acute exposures at three different levels of severity. These guidelines represent concentrations for exposure of the general population for up to 1 hour associated with effects expected to be mild or transient (ERPG-1), irreversible or serious (ERPG-2), and potentially life-threatening (ERPG-3). ERPG values for UF_6 are as follows:

- ERPG-1: 5.0 mg/m^3
- ERPG-2: 15.0 mg/m^3
- ERPG-3: 30.0 mg/m^3

3.3 Shipping Containers and P-10 Sample Tubes

The P-10 tubes are constructed of flurothene (tri-fluoro-chloro-ethylene [TFCE]), as shown in Figure 3-2. The tubes are nominally 8 cm (3.1 in.) long (10 cm [3.9 in.] with the monel closure), 1.25 cm (0.49 in.) outer diameter, and 0.85 cm (0.33 in.) inside diameter. The volume of the tube is 4 cm^3.

The usual complement of eight (8) P-10 tubes has each tube individually heat-sealed into a pocket of a heavyweight (approximately 0.01 cm [0.004 in. or 4 mil]) polyethylene envelope. The envelope is rolled, wrapped in bubble wrap, and surrounded with polystyrene "peanuts" within a 25.9 L (6.85 gal) (30.5 cm diameter x 35.6 cm deep [12 in. x 14 in.]), 25 gauge, steel bucket. The bucket has a ring clamp lid closure and is painted blue.

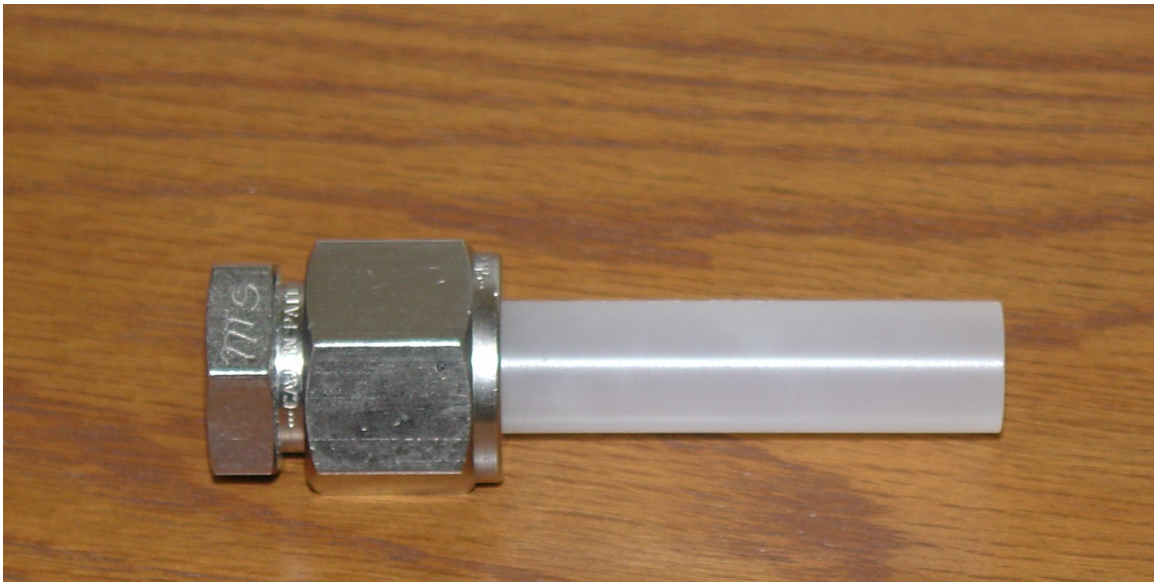


Figure 3-2 P-10 Sample Tube

WEC believes that the two shipping containers were inadvertently sent to the landfill operated by Waste Management, Incorporated (WMI) in Richland County, SC. There is approximately 100 g of UF_6 containing 64 g uranium at an average enrichment of 4.95 percent uranium-235 (^{235}U) in each of the two shipping containers. The 100 g of UF_6 is evenly distributed in the eight

P-10 sample tubes in the bucket. The total uranium amount of 128 g has a radioactivity content of 409.4 microcuries (μ Ci). The isotopic composition of the UF_6 is presented in Table 3-1.

Table 3-1

Isotopic Composition of UF_6 Samples

Radionuclide	Specific Activity, μ Ci/g [a]	Total Activity, μ Ci [b]
U-234	2.767	354.2
U-235	0.106	13.6
U-236	0.002	0.256
U-238	0.323	41.3
	Total	409.4

a. μ Ci/g - microcurie/gram

b. Total activity = specific activity x 128 g uranium total

3.4 The Landfill

The landfill, operated by Waste Management, Incorporated (WMI), has 49.4 ha (122 ac) with landfill activity on a 364-ha (900-ac) site. It accepts 2,087 mt (2,300 t) of solid waste daily. Based on discussions with WMI personnel regarding the location in the landfill where the samples are thought to be, WEC believes subsequent landfill operations resulted in covering the samples to a depth of 6.1 m (20 ft) by a backfill of landfill material and soil.

The landfill has a methane gas recovery system that provides gas for electrical power generation. Since 1999, the South Carolina Energy Office has partnered with the EPA's Landfill Outreach Program (LMOP) in an effort to reclaim and use landfill gas in the state. Landfill gas is produced in a similar manner to anaerobic digestion. The anaerobic conditions within a landfill produce methane and other gases naturally, and these gases migrate to tubes deep within the landfill. The tubes transport the gas to collection stations on the surface, where it goes through a cleaning process to remove harmful and corrosive chemicals prior to electricity generation.

In 2001, Santee Cooper became the first electric utility in the state to generate and offer green power to its customers by utilizing a methane recycling system to generate electricity from the 3.3 Mw (megawatt) Horry County Landfill near Conway, SC. Similar facilities now include the 5.5 Mw system at the landfill in Richland County, which was brought online on February 21, 2006 .

3.5 Potential Long-Term Fate of Uranium Hexafluoride

The long-term disposal of the UF_6 presents potential environmental, health, and safety risks because of its chemical instability. Based on the information developed in Section 3.1, the following progression in the fate of the UF_6 can be hypothesized:

- Due to weight of soil above the two buckets and the 16 P-10 sample tubes within, it is assumed the buckets would be initially crushed, but the P-10 tubes would likely initially remain intact.
- During the decomposition process under the anerobic conditions of the landfill material, and given the added pressure due to overlying soil, the temperature would increase above the UF_6 sublimation temperature. This, along with the added damage associated with the disposal process, the escape of the UF_6 as a gas would be likely.
- Upon escape, the UF_6 gas could interact with metals, yielding among other reaction products metal fluorides and hydrogen.
- An alternate and possibly parallel progression would be contact of the UF_6 with moisture in the soil which would result in UO_2F_2 and HF, both of which are highly soluble and toxic.
- Contact of HF with soil in the form of silicon dioxide (SiO_2, quartz sand) would lead to silicon fluoride salts and water.

Given the above potential processes, and considering there is only 200 g of UF_6 to begin with, the amount of contaminated landfill material and soil would be small. The density of loose sand is 1602 kg/m^3; packed sand 1,682 kg/m^3; and water-filled sand is 1,922 kg/m^3. Assuming the 128 g of U contained in the samples were uniformly mixed and in 1.5 m^3 of loose sand, the concentration would be 0.051 micrograms (μg) U per g of soil. Based on the total activity identified in Table 3-1, this would correspond to 170 picocuries (pCi)/g of soil.

This level can be compared to nominally 1 pCi of natural uranium and its radioactive daughters, including radium-226 [^{226}Ra] and radon. The corresponding activity in a column of soil 6.1 m (20 ft) deep over an area of 1 m^2 would be 11.7 μCi (i.e., [6.1 m] x [1 m^2] x [1,922 kg/m^3] x [1000 g/kg] x [1 μCi/ 10^{-6} pCi] = 11.7 μCi). Therefore, the amount of activity in the samples correspond to the amount of natural uranium and its radioactive daughters in a column of soil 6.1 m (20 ft) deep over an area of 35 m^2 (377 ft^2) (i.e., [409.4 μCi] / [11.7 μCi/m^2] = 35 m^2).

As noted in Section 3.4, the landfill has a methane recovery system. Such systems remove contaminants prior to use of the methane gas in electrical power generation. Should any methane extraction tubing be in the vicinity of the disposed UF_6, it is unlikely that reaction products resulting from contact with soil moisture, such as hydrogen fluoride (HF) could make it into the recovered methane gas. The hydrogen fluoride is very soluble in soil moisture, and would not be in a gaseous form. As a result, any associated uranium reaction products would not be expected to be entrained in any recovered methane.

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4.0 ASSESSMENT METHODOLOGY

In evaluating the potential hazards associated with the UF_6 sample vials, TtNUS took several approaches as outlined below:

- Evaluate maximum exposure scenarios in which the material was released at ground level to evaluate downwind radiation doses and concentrations of hazardous compounds.
- Apply the U.S. Department of Energy (DOE) model (RESRAD) for evaluation of long-term potential risks associate land disposal of radioactive materials.

4.1 Maximum Exposure Scenario

In evaluating the maximum exposure scenario, the entire radioactivity in the UF_6 samples of 409.4 μCi is assumed to be released at ground level under restrictive meteorological conditions that lead to the highest concentrations. Those conditions are assumed to be an F atmospheric stability class with a wind speed of 2 m/s (6.6 ft/s). The U.S. Environmental Protection Agency's (EPA) code CAP-88, Version 2.1 was used in estimating the concentrations at selected downwind distances (EPA 2008). The internal dose conversion factors (DCFs) used in this assessment are those from Federal Guidance 11 (EPA 1988). The dose conversion factors are a function of the solubility class of the chemical compound and the particle size. Since gaseous UF_6 is expected to combine with humidity to form particulate UO_2F_2 and HF fumes, which are soluble, TtNUS selected a D solubility class and a 1 micrometer (μm) particle size for the DCFs.

From a chemical exposure viewpoint, the exposure concentrations of UF_6 can be estimated in a manner consistent with that for the radiation doses by using the normalized time-integrated concentrations, χ/Q, values generated as part of the CAP-88 runs.

4.2 Application of RESRAD 6.4

The RESRAD computer model is designed to estimate radiation doses and risks from RESidual RADioactive materials (ANL 2001). RESRAD 6.4 is the latest version of code since it was first issued in 1989. Since this time, RESRAD has been used widely by the U.S. Department of Energy (DOE), its operations and area offices, and its contractors for deriving limits for radionuclides in soil. RESRAD has also been used by the EPA, U.S. Army Corps of Engineers, U.S. Nuclear Regulatory Commission (NRC), industrial firms, universities, and foreign government agencies and institutions.

The RESRAD code was developed as a multifunctional tool to assist in developing cleanup criteria and assessing the dose or risk associated with residual radioactive material. The code is designed to:

- Compute soil guidelines (concentrations that will comply with dose- or risk-based cleanup or release requirements set forth in various federal and state regulations),
- Compute potential annual doses or lifetime risks to workers or members of the public resulting from exposures to residual radioactive material in soil,
- Compute concentrations of radionuclides in various media (air, surface water, and groundwater) resulting from residual activity in soil, and

- Support an ALARA (as low as reasonably achievable) analysis or a cost benefit analysis that can help in the cleanup decision-making process.

RESRAD adopts a long-term, maximum exposure scenario approach in which the site containing radioactive contamination is eventually returned to public use after periods of up to 1,000 years. The maximum exposure scenario is typically the resident farmer scenario. In cases in which this scenario is not realistic but is plausible, it can generally be assumed to be the most restrictive use and, therefore, may be used to demonstrate that the potential uses for all plausible scenarios will not exceed the 100-mrem/yr dose limit.

All significant exposure pathways for the critical population group are considered, including:

- Direct exposure to external radiation from the contaminated soil material;
- Internal dose from inhalation of airborne radionuclides, including radon progeny; and
- Internal dose from ingestion of
  - Plant foods grown in the contaminated soil and irrigated with contaminated water,
  - Meat and milk from livestock fed with contaminated fodder and water,
  - Drinking water from a contaminated well or pond,
  - Fish from a contaminated pond, and
  - Contaminated soil.

In applying RESRAD to the UF_6 samples, the radioactive inventory of 409.4 μCi is assumed to be initially uniformly distributed a in 1.5 m^3 of loose sand, as outlined previously in Section 3.4. Then, three scenarios were considered:

- Scenario 1: A future excavation scenario in which the contaminated soil ended up on the surface with an area of 10 m^2 and a depth of 0.15 m (i.e., 0.15 m x 10 m^2 = 1.5 m^3)
- Scenario 2: An in-place disposal scenario in which the material remained at a 6.1 m (20 ft) depth but distributed in the prior areal configuration
- Scenario 3: A comparison scenario that considers only radon from natural uranium in the soil. Doses are calculated resulting from radon associated with 1 pCi/g of natural uranium and its radioactive daughters emanating from a volume of soil with the same areal extent of 10 m^2 and a depth of 6.1 m (20 ft).

In applying RESRAD, the default parameters for all pathways were assumed, except in specifying the nature and extent of the contaminated soil. In making the runs, TtNUS selected 1) the inhalation and ingestion DCFs from Federal Guidance 11 (EPA 1998), and 2) the external DCFs from Federal Guidance 12 (EPA 1988). Since the chemical form of the uranium radionuclides in the contaminated soil could be altered over the long-term, TtNUS maintained the RESRAD default DCFs for the uranium radionuclides, which are the highest inhalation and ingestion DCF values for the uranium radionuclides.

5.0 RESULTS AND CONCLUSIONS

Section 3.0 outlined the approaches TtNUS took in evaluating the potential hazards associated with the UF_6 sample vials, which included the following:

- Evaluate worst case scenarios in which the material was released at ground level to evaluate downwind radiation doses and concentrations of hazardous compounds.
- Apply the U.S. Department of Energy (DOE) model (RESRAD) for evaluation of long-term potential risks associated with land disposal of radioactive materials

The results of this evaluation are presented below.

5.1 Maximum Exposure Scenarios

In evaluating the maximum exposure scenario, the entire radioactivity in the UF_6 samples of 409.4 μCi is assumed to be released at ground level under restrictive meteorological conditions that lead to the highest concentrations. The results of the CAP-88 runs are presented in Table 5-1 in terms of the committed effective dose equivalent (CEDE) versus downwind distance and the associated normalized time-integrated air concentration, χ/Q.

Table 5-1

Radiation Doses for Maximum Exposure Scenario

Downwind Distance, m	Dose, mrem	χ/Q, s/m^3
100	5.53×10^{0}	5.80×10^{-3}
250	9.61×10^{-1}	9.96×10^{-4}
500	2.56×10^{-1}	2.61×10^{-4}
750	1.19×10^{-1}	1.19×10^{-4}
1000	6.88×10^{-2}	6.79×10^{-5}

Based on these results the radiation dose associated with the maximum exposure scenario is 5.5 mrem/yr at 100 m and 0.96 mrem/yr at 250 m. This can be compared to background radiation levels of nominally 300 mrem/yr and the EPA annual dose criterion of 100 mrem/yr to members of the public from all human-related sources.

From a chemical exposure viewpoint, the exposure concentrations of UF_6 can be estimated in a manner consistent with that for the radiation doses by using the χ/Q values in Table 5-2. Assuming a release of 200 g of UF_6, and assuming a time integration of 1 hr (3,600 s) corresponding to the AIHA reference exposure period, the estimated concentrations at the downwind distances of interest are presented in Table 5-2. Estimates are also provided for a total plume passage time of 100 s.

Table 5-2

UF_6 Concentrations for Maximum Exposure Scenario

Downwind Distance, m	χ /Q, s/m^3	UF_6 Concentration, mg/m^3 [a]	
		1 hr[a]	100 s[b]
100	5.80×10^{-3}	3.22×10^{-1}	1.16×10^{1}
250	9.96×10^{-4}	5.53×10^{-2}	1.99×10^{0}
500	2.61×10^{-4}	1.45×10^{-2}	5.22×10^{-1}
750	1.19×10^{-4}	6.61×10^{-3}	2.38×10^{-1}
1000	6.79×10^{-5}	3.77×10^{-3}	1.36×10^{-1}

a. UF_6 concentration = (200 g) (χ /Q, s/m^3) (10^3 mg/g) / (3600 s)
b. UF_6 concentration = (200 g) (χ /Q, s/m^3) (10^3 mg/g) / (100 s)

The estimated maximum exposure over a period of 1 hour to UF_6 is 0.32 mg/m^3 at 100 m and 0.055 mg/m^3 at 250 m. Assuming the concentrations occurred only during a plume passage time of 100 s, the estimated concentrations would be 11.6 mg/m^3 at 100 m and 2.0 mg/m^3 at 250 m. These concentrations can be compared with the 1 hr ERPG values for UF_6 are as follows:

- ERPG-1: 5.0 mg/m^3
- ERPG-2: 15.0 mg/m^3
- ERPG-3: 30.0 mg/m^3

The results indicate that the concentrations would be below the ERPG-1 values at 100 m for a 1 hr reference exposure period. The concentrations during a 100 s plume passage period would be below the instantaneous value of ERPG-2 at 100 m.

As an extension of the maximum exposure scenario, the potential for direct contact with the UF_6 has been considered. This could potentially occur, for example, at sometime in the future should excavation occur at the landfill. The material is corrosive, and harmful by inhalation, ingestion or skin absorption. The effects of exposure to the material may be delayed. Should a worker come into direct contact with the UF_6 sample tubes, and be subject to a skin exposure, there is potential for an acid burn, which is treatable with calcium gluconate.

5.2 RESRAD Modeling

In applying RESRAD to the UF_6 samples, the radioactive inventory of 409.4 μCi is assumed to be initially uniformly distributed in 1.5 m^3 of loose sand, as outlined previously in Section 3.4. Then, three scenarios were considered:

- Scenario 1: A future excavation scenario in which the contaminated soil ended up on the surface with an area of 10 m^2 and a depth of 0.15 m (i.e., 0.15 m x 10 m^2 = 1.5 m^3)
- Scenario 2: An in-place disposal scenario in which the material remained at a 6.1 m (20 ft) depth but distributed in the prior areal configuration

- Scenario 3: Radon from natural uranium in the soil. Doses are calculated resulting from radon associated with 1 pCi/g of natural uranium and its radioactive daughters emanating from a volume of soil with the same aeral extent of 10 m^2 and a depth of 6.1 m (20 ft).

The results of the RESRAD runs for the three long-term exposure scenarios are presented in Table 5-3.

Table 5-3

RESRAD Results for Exposure Scenarios

Time, yr	Dose, mrem/yr[a]		
	Scenario 1	Scenario 2	Scenario 3
0	$4.07x10^{0}$	$7.39x10^{-10}$	$1.13x10^{1}$
1	$3.87x10^{0}$	$5.06x10^{-9}$	$1.14x10^{1}$
3	$3.51x10^{0}$	$2.55x10^{-8}$	$1.18x10^{1}$
10	$2.50x10^{0}$	$1.94x10^{-7}$	$1.27x10^{1}$
30	$9.30x10^{-1}$	$1.04x10^{-6}$	$1.42x10^{1}$
100	$2.33x10^{-1}$	$3.11x10^{-6}$	$1.48x10^{1}$
300	$5.59x10^{-2}$	$6.19x10^{-2}$	$1.18x10^{1}$
1000	$1.43x10^{-2}$	$1.77x10^{-2}$	$4.38x10^{1}$

a. 1 mrem/yr = 0.001 mSv/yr

The RESRAD results indicate maximum annual doses of 4.1 mrem/yr for Scenario 1, 0.018 mrem/yr for Scenario 2, and 44 mrem/yr for Scenario 3. Based on these results, the doses due to natural uranium and its radioactive daughters, giving rise to radon exposures would be higher than doses due to the UF_6 exposure scenarios.

In reviewing the RESRAD output for the three scenarios, Scenario 1 is dominated by non-water pathways (primarily external exposure to ground contamination and inhalation), Scenario 2 is dominated by groundwater pathways, and Scenario 3 is dominated by natural radon. Both Scenarios 1 and 2 account for buildup of radon from the decaying initial uranium radionuclides. TtNUS has provided the RESRAD input files and the Summary Reports for each scenario. Those files provide detailed information on contributions by radionuclide and exposure pathways.

5.3 Conclusions

WEC has no physical evidence to substantiate that this material was actually disposed of at the Richland County Landfill facility. Hypothetically, if the disposal of the UF_6 sample tubes were improperly disposed of in the Richland County Landfill, the potential radiation and chemical exposure risks posed by the UF_6 sample tubes are small when compared to exposure and natural background radiation levels.

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6.0 REFERENCES

ANL 2001. Yu,C., A. Zielen, J. Cheng, D. LePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo, W. Williams, and H. Peterson User's Manual for RESRAD Version 6, ANL/EAD-4, Environmental Assessment Division Argonne National Laboratory (July 2001). http://web.ead.anl.gov/resrad/home2/

ANL 2008. Argonne National Laboratory, "Information on Uranium Hexafluoride" (2008). http://web.ead.anl.gov/uranium/guide/ucompound/propertiesu/hexafluoride.cfm

EPA 1988. Eckerman, K.F., et al., Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, EPA-520/1-88-020, Federal Guidance Report No. 11, prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, D.C (1988).

EPA 1993. Eckerman, K.F., and J.C. Ryman, 1993, External Exposure to Radionuclides in Air, Water, and Soil, Exposure to Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance, EPA 402-R-93-076, Federal Guidance Report No. 12, prepared by Oak Ridge National Laboratory, Oak Ridge, TN, for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C (1998).

EPA 2008. U.S. Environmental Protection Agency, "CAP-88 Computer Code" (2008). http://www.epa.gov/radiation/assessment/CAP88/index.html

NRC 2008. U.S. Nuclear Regulatory Commission, "Current Event Notification Report for February 15, 2008".

WEC 2008. Letter from G. Couture of Westinghouse Electric Company to G. Superintendent of Waste Management, Incorporated, "Westinghouse Lost Uranium Hexafluoride Sample Vials", LTR-EHS-08-24 (February 18, 2008).

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