APPENDIX D

Typical Remediation Site Characteristics

D-1. Uranium and Thorium Mines and Mills.

a. Facility Operation Description. Uranium is mined using both open pits and underground shafts. Some facilities are now using a subsurface pumping and leaching process. Uranium mills are often co-located with the mines. A majority of the mines in the US are located in the states of Arizona, New Mexico, Utah, and Colorado, but active leaching also occurs in Nebraska and Texas. The majority of the contaminants are located in tailings from the mills and the mines. Co-mingled hazardous components such as Arsenic, and acids are commonly found at these sites.

b. Types of Radiation Expected. Alpha, beta, gamma and neutron radiation can be expected from these sites.

c. Types of Sources Present. Uranium 238, 235, and 234 and all their decay progeny can be found at these sites. Thorium-232 and 230 and their decay progeny may also be present at some sites. Since the mills selectively extracted uranium, the decay progeny at these sites can be expected to not be in equilibrium. There will still be residual uranium or thorium in the mill tailings, and can be expected to contain greater levels of decay progeny.

d. Radioactive Contamination Potential. There is nearly always contamination from mining and milling operations. Great piles of mine-and-mill tailings are left on-site. Often consolidation points from nearby mines exist, where ores were consolidated for transport to the mills. Surface and ground water contamination is common from rain percolating through the waste piles, and running off sites. Establishment of background can be troublesome because the naturally elevated background radiation is primarily attributable to the elevated Uranium in the local and subsurface soils.

e. Radioactive Waste Generated. Large quantities of source material, 11e.(2) byproduct material or residuals of ore processing prior to 1978, may be encountered.

f. Potentially Contaminated Areas. Mines, mills access roads, wide surrounding areas, associated heavy equipment, hand tools, transport vehicles, PPE, ground water, creeks and rivers, and workers' houses can be expected to be contaminated. Cross contamination is a common problem.

D-2. Nuclear Weapons Facilities.

a. Facility Operation Description. The nuclear weapons facilities considered here are those where nuclear weapons are inspected, stored, and maintained. TRU materials and wastes may be present. Both radioactive wastes and co-mingled wastes may be present as byproducts of the processes and operations in the facilities. The weapons were disassembled, inspected, repaired, reassembled, and stored until shipped from these facilities.

b. Types of Radiation Expected. Alpha, beta, gamma and neutron radiation can be expected.

c. Types of Sources Present. The radioactive material can be considered a sealed source when a weapon is assembled. During inspection and maintenance, the radioactive material is an unsealed source. Examples of radionuclides present in nuclear weapons are uranium-233, and -235, plutonium-239 and -241, americium-241, and hydrogen-3. Depleted uranium is also used in testing and training for weapons maintenance.

d. Radioactive Contamination Potential. There is little potential for radioactive contamination when a weapon is assembled unless it is subjected to severe physical damage such as a fire. When a weapon is disassembled, there is a slight potential for contamination. This potential increases if the radioactive material is damaged in any way during inspection and maintenance.

e. Radioactive Waste Generated. Very small volumes of slightly contaminated solid waste can be generated during inspection and maintenance. No significant amount of liquid radioactive waste is generated.

f. Potentially Contaminated Areas. Areas of potential contamination include disassembly, inspection, maintenance, and reassembly areas; radioactive waste handling and packaging areas; and decontamination facilities. Sinks, drains, trash receptacles, and formerly used radioactive waste disposal cells are probable contaminated areas.

D-3. Research Laboratories.

a. Facility Operation Description. Depending on its mission, a research laboratory may be involved in a wide variety of activities, including the analysis of materials activated by neutron radiation, the effects of radiation exposure on animals, and the use of radioactive tracers in chemistry experiments. Various radionuclides may be used in a typical laboratory environment or may be used in closed, shielded cells, or glove boxes to protect personnel from radioactive hazards. A reactor or accelerator may also be used at the facility.

b. Types of Radiation Expected. Depending on the facility mission, a number of different radionuclides may be used, and alpha, beta, X, gamma, or neutron radiation can be expected.

c. Types of Sources Present. Sealed, partially sealed, and unsealed sources can be expected to be used.

d. Radioactive Contamination Potential. There is a high potential for contamination in any area of a laboratory where unsealed sources are used.

e. Radioactive Waste Generated. Moderate to large volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste can also be generated. Research labs characteristically produce larger quantities of mixed or co-mingled wastes compared to radioactive wastes.

f. Potentially Contaminated Areas. Areas of potential contamination include:

- Laboratory areas (bench tops, fume hoods, glassware, centrifuges, scintillation counters, hot cells, glove boxes, and refrigerators used for radioactive material storage)
- Animal cage areas
- Solid radioactive waste-handling and packaging areas
- Liquid radioactive waste system (tanks, pumps, valves, piping)
- Ventilation system (ducting, filters, filter housings)

D-4. Medical Facilities.

a. Facility Operation Description. Medical facilities perform a variety of diagnostic and therapeutic procedures using radioactive materials and radiation-producing machines. For diagnostic procedures, radioactive material may be injected into a patient in liquid form or taken orally. Radiation-producing machines such as X-ray units and computerized tomography scanners may be used. For therapeutic procedures, radioactive material may be injected into a patient in liquid form, taken orally, or implanted in solid form. These implanted sources may remain in the patient or can be removed later. Accelerators and highly radioactive cobalt-60 source capsules are also used for radiation therapy.

b. Types of Radiation Expected. Beta, X, gamma, neutron and charged particle radiation sources could occur.

c. Types of Sources Present. Sealed, partially sealed, and unsealed sources can be expected to be used.

d. Radioactive Contamination Potential. There is a high potential for contamination where unsealed sources are used for diagnosis or therapy. Most unsealed radionuclides used in medicine have short half-lives and, therefore, may not present major decontamination problems for decommissioning. There is a minimum potential for contamination when sources are implanted if the sources are mishandled. There is a slight potential for contamination from sealed sources such as high radioactivity cobalt-60 sources that are used in radiation therapy units. Contamination may occur from activation products created by high-energy accelerators (> 10 million electron volts) used in research-oriented medical facilities.

e. Radioactive Waste Generated. Small to moderate volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste will be generated.

f. Potentially Contaminated Areas. Areas of potential contamination may include the following:

- Radio-pharmacies that are producing, storing, or dispensing radioactive drugs
- Laboratories where liquid sources are prepared for use
- Operating rooms where sources are implanted
- Patients' rooms and examination rooms where patients who have been administered radioactive materials are located
- Nuclear medicine hot labs
- Solid radioactive waste-handling, packaging, and storage areas
- Liquid radioactive waste system (tanks, pumps, valves, piping)
- Areas where liquid radioactive sources are stored prior to preparation for administration

D-5. Pool Reactors and Neutron Radiography Reactors.

a. Facility Operation Description. These reactors are atmospheric-pressure, water-cooled assemblies generally used to produce long-term, steady-state fluxes of thermal neutron radiation. Some reactors can also produce a high flux of thermal neutron radiation for a very short period of time. The neutron radiation is made available for use outside the reactor by beam ports which penetrate the reactor structure. Items to be irradiated are placed in front of the beam ports.

b. Types of Radiation Expected. Primarily gamma and neutron radiation are expected from the reactor. Beta and gamma radiation are expected from the irradiated test items, reactor structures, or impurities in the cooling water.

c. Types of Sources Present. The reactor fuel elements can be considered a sealed source because the uranium fuel and fission products are contained in cladding. Impurities in the cooling water that become activated can be considered an unsealed source. Any radioactive material resulting from neutron activation of test items or reactor structures could be classified as sealed or unsealed sources based upon the types of materials being activated. Sealed and partially sealed sources will be used for instrument checks and calibrations.

d. Radioactive Contamination Potential. The potential for contamination in a pool-reactor facility can be characterized as moderate. The radioactive material in the cooling water, which results from neutron activation of impurities, may be pumped through the cooling system and deposited in pipes, valves, pumps, and other system components. When these components are opened for maintenance or repair, or if leaks occur, contamination is likely. The inventory for the coolant radioactive material will be increased if the fuel cladding leaks or is damaged in some manner, releasing fission products into the cooling water. If neutron activation of test items or the structures surrounding a reactor occurs, the radioactive material will be fixed.

e. Radioactive Waste Generated. Moderate volumes of solid and liquid radioactive wastes will be produced at this type of facility.

f. Potentially Contaminated Areas. Areas and other sources of potential contamination include:

- Area housing the reactor
- Areas housing the reactor auxiliary system
- Test items
- Beam ports and equipment used to handle activated test items
- Maintenance areas
- Solid radioactive waste-handling and packaging areas
- Liquid radioactive waste system (tanks, pumps, valves, piping)
- Ventilation system (ducting, filters, filter housings)
- Decontamination areas

D-6. Power Reactors.

a. Facility Operation Description. The majority of the power reactors in the United States are pressurized water reactors (PWR) or boiling water reactors (BWR). Other types of reactors include gas-cooled, liquid metal, and heavy water. The reactor fuel produces large amounts of heat as a result of the fission process. This heat is used to generate steam directly in a BWR or is carried by the coolant in the primary system to the steam generator in a PWR or other indirect-cycle reactors. The heat is transferred through the walls of the tubes in the steam generator to the water in the secondary side of the steam generator. The temperature is

sufficiently high to change the secondary water into steam. In most plants, the steam travels to a turbine that drives an electric generator to produce electrical power.

b. Types of Radiation Expected. Primarily, gamma and neutron radiation are expected from the reactor. Beta and gamma radiation are expected from the irradiated reactor structures or impurities in the coolant. Alpha, beta, and gamma radiation may arise from the spent fuel rods stored at the facility.

c. Types of Sources Present. The fuel rods inside the reactor itself are designed to contain the uranium fuel and fission products within the cladding. The fuel rods are the main source of gamma and neutron radiation in the reactor. However, cladding failure, or the presence of tramp uranium on reactor surfaces, may result in the release of radioactive fission products to the surrounding coolant. Activated impurities and corroded activated metals in the reactor coolant can be considered an unsealed source. Activated materials in the reactor structure can also be the source of gamma and beta radiation.

d. Radioactive Contamination Potential. The potential for contamination in a power reactor facility is greater than that in other facilities primarily because of repair and maintenance activities. The radioactive material in the reactor coolant, which results from neutron activation of corrosion products and fission products from fuel-cladding failures or tramp uranium, is carried through the system and deposited in pipes, valves, pumps, the steam generator, and other components. When these components are opened for maintenance or repair, or if leaks occur, contamination is likely. The radioactive material inventory will be greatly increased if a substantial number of fuel-cladding leaks occur or the fuel is damaged in some manner, releasing fission products into the primary coolant. When neutron activation of the structures surrounding a reactor occurs as the system ages, the radioactive material is fixed but may become removable if the material is dislodged through corrosion and erosion.

e. Radioactive Waste Generated. Great volumes of solid and liquid radioactive waste can be produced at this type of facility.

f. Potentially Contaminated Areas. Areas of potential contamination include:

- Area housing the reactor
- Areas housing reactor auxiliary systems
- Maintenance areas
- Equipment decontamination areas
- Personnel decontamination areas
- Protective clothing laundry area
- Respiratory protective equipment decontamination area
- Solid radioactive waste-handling and packaging area

- Liquid radioactive waste-system (tanks, pumps, valves, piping)
- Ventilation systems (ducting, filters, filter housings)

D-7. Accelerator Facilities.

a. Facility Operation Description.

(1) Particle accelerators are radiation-producing machines used for medical, industrial, and research purposes.

(2) Electron linear accelerators (linacs) are used to produce a primary beam of electron radiation (similar to beta radiation though highly directive and of much greater energy) or a secondary beam of X-radiation (similar to gamma radiation) for use in therapy. The patient is positioned relative to the output beam port of an electron linacs and the machine is energized for the time required to produce the amount of radiation desired for the therapy.

(3) Electron linacs are used in industrial applications to produce a secondary beam of X-radiation. The radiation is used for the radiography of such items as welds, castings, and munitions. Electron linacs are used in research to determine the effects of irradiation on various materials under study.

(4) Other types of particle accelerators are used for engineering physics research.

b. Types of Radiation Expected. Electrons make up the primary beam of electron linacs. If the output energy of electron linacs exceeds about 10 million electron volts, neutrons may be produced. Other types of particle accelerators emit, protons, alpha particles or other nuclear particles, resulting in secondary radiations and activation of materials. The activated material normally decays by beta- (positive or negative) and gamma-radiation emission.

c. Types of Sources Present. Linacs incorporate radioisotopes of various species in their sources and in some of their targets. If the output energy of an electron linac exceeds about 10 million electron volts, neutron radiation may be produced. This neutron radiation and output from other types of particle accelerators may activate areas of the device around the output beam port and the structure surrounding the device. If this occurs in solid objects, the radioactive material is considered a sealed source; activated liquids or gases will usually be in unsealed form and more mobile.

d. Radioactive Contamination Potential. There are several different types of particle accelerators. Each type and its specific operation must be reviewed to determine the potential contamination.

e. Radioactive Waste Generated. No liquid or solid radioactive waste is expected unless the electron linac exceeds 10 million electron volts, in which case small volumes of solid, liquid, or gaseous waste resulting from neutron activation may be produced. Small volumes of radioactive waste may be generated by other types of particle accelerators.

f. Potentially Contaminated Areas. If the output energy of electron linacs is less than 10 million electron volts, none of the surrounding structure will be contaminated. Energies greater than 10 million electron volts from electron linacs or other particle accelerators may activate components, targets, and surrounding structures, which may result in contamination from loose or disturbed material, during maintenance of the devices, and during decommissioning of the devices.

D-8. Radiographic Facilities.

a. Radiographic Facilities using Electromagnetic Radiation. The primary purpose of radiographic facilities is to nondestructively test items for defects. For example, welds are radiographed to reveal any hidden porosity or cracks, castings are radiographed to reveal any hidden voids, and munitions are radiographed to check for proper assembly. Electromagnetic radiation penetrates a test item and exposes a sheet of film or array of detectors in the same manner that light exposes film or video systems to produce an image. Radiographic films are processed and checked for defects in the item radiographed. The electromagnetic radiation needed for radiography may be produced by a sealed source of radioactive material such as cobalt-60 or iridium-192, or by X-ray machines or election linacs. Sealed radioactive sources must be housed in shielded containers when not in use. The containers may be fixed or portable. X-ray machines require no shielding when not in use because radiation is produced only when a machine is electrically energized. Shielding is required when a machine is energized. X-ray machines may be installed in a fixed configuration or may be portable.

(1) Types of Radiation Expected. Gamma radiation is expected from sealed radioactive sources. Linacs may be used to generate the radiographic beam and their characteristic radiation and waste potential should be expected.

(2) Types of Sources Present. When radioactive material is used, the sources will be sealed.

(3) Radioactive Contamination Potential. There is no potential for contamination from an X-ray machine or from a sealed source unless the source is damaged in a manner that breaches the integrity of the material used to encapsulate the radioactive material, or unless the sealed source leaks for any other reason.

(4) Radioactive Waste Generated. None is expected from most radiographic systems. However, if linacs are used to generate the radiographic beam, the sources and targets are probable waste sources.

(5) Potentially Contaminated Areas. There are none, except in the case of linac-generation radiographic systems.

b. Radiographic Facilities using Neutron Radiography. Neutron radiography is used to detect moisture and corrosion in bonded honeycombed structures and to test other materials. The secondary radiations created by the neutrons reacting with the material are detected and displayed on monitors that have the capability of digital and imaging enhancement. Most frequently, sources such as radium, americium, or plutonium can be used as sources of alpha radiation impinging on beryllium. The beryllium is activated by alpha radiation to emit neutrons. The radiography occurs in a shielded and interlocked bay, which is accessible only when the source is withdrawn into a shield.

(1) Types of Radiation Expected. Neutrons from the source are to be expected. Due to neutron activation, alpha, beta, neutron, and gamma radiation may result from irradiated test items and structural materials.

(2) Types of Sources Present. The source is typically sealed hermetically. Source encapsulation may fail, causing the direct release of alpha and neutron radiation. Any radioactive material resulting from activation of test items or structural material can be classified as sealed or unsealed, based on the types of material being activated.

(3) Radioactive Contamination Potential. The potential for contamination is low for properly used and maintained sources. Abandoned or lost source capsules present a serious hazard. It must be noted that the beryllium used to produce the secondary neutron radiation is a very toxic heavy metal. Neutron activation of test items or the structure surrounding the source of neutrons could result in contamination if the material were dislodged and became loose and spreadable.

(4) Radioactive Waste Generated. Very little waste will be generated that is radioactive so long as proper operational, maintenance, and storage practices are followed. Decommissioning of radiographic equipment will generate the largest portion of LLRW of the entire use cycle. The potential for uncontrolled radioactive waste is greater in the event of equipment abandonment, fire, or other catastrophic event.

(5) Potentially Contaminated Areas. Areas of potential low-level contamination are restricted to the radiography bay and test-material-handling areas.

D-9. Radioluminous-device Storage Facilities.

a. Facility Operation Description. These facilities store new and used radioluminous devices such as clocks, instruments, gunsights, night-vision testers, exit signs, and radioluminescent airfield lighting systems.

b. Types of Radiation Expected. Radioluminescent devices use radioactive sources to energize phosphorescent elements or chemicals. The radioactive materials primarily used to generate luminosity are tritium, promethium-147, krypton-85, and radium-226. Tritium and promethium-147 emit beta radiation only, krypton-85 emits beta and gamma radiation, and radium-226 emits alpha and gamma radiation. Decay products of radium-226, which are radioactive, will also emit beta radiation. Radon-222 is a gaseous decay product and poses the risk of inhalation.

c. Types of Sources Present. Radioluminous devices may consist of instrument faces with the radiation source painted on or may incorporate vials or capsules of radioluminous materials. Because the devices frequently rely on tritium or radium as primary radiation sources, they have great potential to be effectively unsealed. This is because tritium may be a gaseous radioisotope, and because one of the daughters of the decay of radium is radon, which is a gaseous radioisotope. Guaranteed seals, even of encapsulated radioluminous materials, are difficult to achieve and should not be expected.

d. Radioactive Contamination Potential. Radioluminous paint is a probable surface and water contaminant when scraped or dissolved off its substrate. The most serious and difficult contamination arising from radioluminous devices is from radium-doped paint.

e. Radioactive Waste Generated. Damaged equipment components that are painted with radioluminous materials may be radioactive waste. Maintenance of radioluminous systems will generate contaminated cleanup materials. Radioluminous materials characteristically produce gaseous radioactive contaminants. Tritium and radon are readily soluble in water, are easily spread, and can contaminate biological organisms, soil, and ground water. The great mobility of radioluminescent-generated waste makes it difficult to clean up. Fortunately, the low energy levels and the small volumes of the original sources commonly encountered will lessen the environmental impact.

f. Potentially Contaminated Areas. There are none, provided the device containing the radioactive material remains intact. Devices with tritium or radium-226 should be treated as suspect to having leakage because of the gaseous radioisotopes involved.

D-10. Depleted Uranium Usage and Storage Facilities.

a. Facility Operation Description. Depleted uranium is used to manufacture various types of munitions. These munitions are stored in various facilities and are used in test and practice firings as well as actual warfare. Depleted uranium has been used as armor in some military vehicles and as counterweights in aircraft. Depleted uranium is also used for shielding radiography and teletherapy sources.

b. Types of Radiation Expected. Alpha, beta, gamma and neutron radiation can all be expected. Additionally, the radioactive decay of the Uranium will produce a sequence of daughter radioisotopes, each of which generates its own characteristic suite of ionizing radiation. Uranium is also a kidney toxin and in some cases the chemical toxicity may be more of a hazard than the radiation exposure. Controls should be based on the more limiting of the chemical or radiological exposures.

c. Types of Sources Present. The depleted uranium in the stored munitions is encased in aluminum or painted, so this source is considered sealed if the case or paint is intact. After the munitions are fired, the sources would be unsealed because the depleted uranium shatters and is dispersed. Depleted uranium used for shields is usually encased in steel and is considered a sealed source.

d. Radioactive Contamination Potential. Airborne dust, machine shavings, cutting lubricants, etc., will arise from the fabrication of components from depleted uranium. Waste disposal areas, water drains, and ventilation ducts will be contaminated by the depleted uranium. Once assembled, there is no potential while the munitions are in storage. After the munitions are fired, there will be contamination of target areas and target materials.

e. Radioactive Waste Generated. There is little from storage except for radon-222 (inhalable alpha radiation source) produced as a decay daughter. Large fragments of the depleted uranium dispersed after firing and the contaminated targets may be collected and disposed of as waste. Small fragments and uranium oxide dust are not collected and are generally dispersed around the target site. The volumes and dispersal of this contamination are substantial.

f. Potentially Contaminated Areas. Firing ranges and targets are areas of contamination.

D-11. Maintenance Shops Repairing Components Containing Magnesium-Thorium Alloys and Depleted Uranium.

a. Facility Operation Description. Machine shops at Air Force Logistics Command Bases repair aircraft parts consisting of depleted uranium and magnesium-thorium alloys by machining, cutting, drilling, welding, and grinding.

b. Types of Radiation Expected. Alpha, beta, gamma, and X-ray from thorium-232 and uranium-238, and radionuclides resulting from their decay are expected. Uranium is also a kidney toxin and in some cases the chemical toxicity may be more of a hazard than the radiation exposure. Controls should be based on the more limiting of the chemical or radiological exposures.

c. Types of Sources Present. Depleted uranium as aircraft counterweights and aircraft components manufactured from magnesium-thorium alloys are considered sealed sources except during repair operations which remove metal.

d. Radioactive Contamination Potential. There is no potential while the parts are in service or storage. Contamination results from machining, cutting, drilling, welding, and grinding operations.

e. Radioactive Waste Generated. Grindings, filings, grinding oils, and broken parts are disposed of as radioactive waste. During grinding of magnesium-thorium alloys, water is used to prevent fires. This water is collected in the hood sump and the water is filtered prior to release to the environment. Both liquid filters and high-efficiency particulate air filters for the hoods are disposed of as radioactive waste. The waste volume generated is not large enough to require a specific on-site storage facility.

f. Potentially Contaminated Area. This is limited to the hoods, exhaust ductwork, and immediate area in which repair operations are conducted.