DEFENSE NUCLEAR FACILITIES SAFETY BOARD

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February 19, 1997

The Honorable Charles B. Curtis
Acting Secretary of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Mr. Secretary:

The Defense Nuclear Facilities Safety Board (Board) and its staff have been reviewing the safety of uranium-233 (^{233}U) in storage within the defense nuclear facilities complex of the Department of Energy (DOE). Enclosed for your consideration is a report that documents this review. The facilities addressed by the enclosed report include those located at the Idaho National Engineering Laboratory, the Los Alamos National Laboratory, the Oak Ridge National Laboratory, and the Lawrence Livermore National Laboratory.

We are aware of the recent highly enriched uranium vulnerability assessment completed by DOE that addresses issues associated with uranium on a broader basis. The enclosed report is based on more than 6 months of review and addresses the specific hazards associated with ^{233}U. The Board hopes that it will be of assistance to the DOE.

Sincerely,

John T. Conway
Chairman

c: The Honorable Thomas P. Grumbly
The Honorable Alvin L. Alm
The Honorable Tara J. O'Toole
The Honorable Victor H. Reis
Dr. Terry R. Lash
Mr. Mark B. Whitaker, Jr.

Enclosure

DNFSB/TECH-13

URANIUM-233 STORAGE SAFETY AT DEPARTMENT OF ENERGY FACILITIES

Defense Nuclear Facilities Safety Board

Technical Report

February 1997

URANIUM-233 STORAGE SAFETY AT DEPARTMENT OF ENERGY FACILITIES

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1. INTRODUCTION

The long-term availability of sufficient amounts of uranium was a matter of concern in the early years of the nuclear era. Demand for uranium was projected to exceed supply. In response to this concern, the United States Government investigated various concepts for the production and utilization of uranium-233 (^{233}U). This isotope of uranium can be created in a nuclear reactor from the irradiation of the relatively more abundant thorium-232. The ^{233}U thus created had potential uses in nuclear reactors as fuel and in the nuclear weapons program. Both uses were investigated in several programs from the 1950s through the 1970s; however, no current uses are anticipated for this material, and it is the safe storage of the ^{233}U residuals of these programs that is the subject of this report.

This report examines the safety of ^{233}U stored at several sites in the Department of Energy's (DOE) complex. DOE has assessed the vulnerabilities associated with ^{233}U reactor fuel in its spent fuel vulnerability assessment (U.S. Department of Energy, November 1993) and those associated with other ^{233}U in its highly enriched uranium (HEU) vulnerability assessment (U.S. Department of Energy, December 1996). In addition, corrective actions regarding the vulnerabilities associated with Oak Ridge National Laboratory's (ORNL) Molten Salt Reactor Experiment (MSRE) were captured by DOE in its Implementation Plan for Defense Nuclear Facilities Safety Board (Board) Recommendation 94-1 (U.S. Department of Energy, February 28, 1995). The purpose of this report is to consolidate the safety issues and vulnerabilities associated with this unique and hazardous isotope of uranium.

With potential actions affecting stored ^{233}U spread across so many DOE initiatives, the focused attention required to deal adequately with its elevated hazards may not be available. Some indications of difficulty have already surfaced. It currently appears that DOE may not be able to meet the schedule for MSRE corrective action commitments made in the 94-1 Implementation Plan. Corrective actions needed for spent nuclear fuel containing ^{233}U are included in the corrective action plan associated with the spent nuclear fuel vulnerability assessment. In addition, the corrective actions associated with the HEU vulnerability assessment have yet to be developed and promulgated. To maximize the effectiveness of corrective actions, and to ensure that all vulnerabilities are identified and addressed and corrective actions tracked to conclusion, it is important to bring together all the salient information in one place and then develop a comprehensive plan for an effective path forward.

The physical forms of ^{233}U considered in this report are metals, compounds, and solutions; also included are scrap materials, which are mixtures of uranium with other substances. In addition, ^{233}U in the form of irradiated or unirradiated reactor fuel is addressed.

A significant amount (more than 50 percent) of the separated ^{233}U in the DOE complex is stored at ORNL (Oak Ridge National Laboratory, October 10, 1996). Other sites with greater than kilogram quantities of separated ^{233}U include the Idaho National Engineering Laboratory

(INEL), the Los Alamos National Laboratory (LANL), and the Lawrence Livermore National Laboratory (LLNL). The sites storing significant amounts of ^{233}U in the form of nuclear reactor fuel are ORNL (at the MSRE), INEL, and the Savannah River Site (SRS).

The remainder of this document is organized as follows. Section 2 addresses some unique hazards associated with ^{233}U. Section 3 presents a description of storage conditions at DOE sites with separated ^{233}U. Next is a short discussion of issues associated with ^{233}U contained in spent nuclear fuel. Finally, Section 5 presents conclusions of the study. The report ends with several appendices, a glossary of acronyms and abbreviations, and a list of references.

2. UNIQUE HAZARDS ASSOCIATED WITH URANIUM-233

Because of its relatively short half-life as compared with ^{238}U and ^{235}U, ^{233}U poses some unique hazards (see also Appendices A and B). However, the dominant concern with this isotope is that it usually has a trace level of ^{232}U associated with it. ^{232}U has a very high specific activity (21 curies per gram), and its decay chain contains a series of short-lived isotopes culminating in the beta decay of the isotope thallium-208 (^{208}Tl), which is accompanied by emission of a very high-energy gamma ray (2.6 million electron volts [MeV]).

^{232}U and ^{233}U also have specific alpha activities 10^7 times higher and 4.4×10^3 times higher than ^{235}U, respectively. These isotopes must be handled in gloveboxes to minimize the possibility of inhalation by workers. The alpha activity increases with time, as the short-lived decay products of ^{232}U build up to equilibrium in about 10 years. Also, the high specific alpha activities of ^{233}U and its decay products can cause high neutron production; this occurs through (α,n) reactions when they are mixed with such elements as fluorine and aluminum that have high probabilities for this reaction.

At a concentration of ^{232}U in the ^{233}U above about 100 parts per million (ppm), the specific alpha activity becomes comparable to that of weapons-grade plutonium, especially as the radioactive decay products of ^{232}U approach equilibrium with the uranium itself. Thus, concerns similar to those associated with the packaging of plutonium in contact with plastic arise; in contrast with other uranium isotopes, radiolysis, gas generation, container pressurization, and corrosion are all issues to be addressed.

As discussed above, ^{232}U also poses a hazard, unique among the uranium isotopes, because of the 2.6 MeV gamma that is emitted by the radioactive decay product ^{208}Tl. A typical package containing 3 kilograms (kg) of ^{233}U (with approximately 100 ppm ^{232}U) would generate a field of more than 25 rem per hour (rem/h) of gamma radiation 1 ft from the package (see Appendix C) (Oak Ridge National Laboratory, October 10, 1996). Thus, the storage and handling requirements for ^{233}U include substantial shielding to protect workers and the public.

3. PRESENT STORAGE CONDITIONS FOR SEPARATED URANIUM-233 AT DEPARTMENT OF ENERGY SITES

The separated ^{233}U inventories at various DOE sites are summarized in Table 1.

Table 1. Masses of Separated ^{233}U at DOE Sites (kg)

Site	^{233}U Mass (kg)
ORNL	427.5
INEL (ICPP)	317.4
INEL (RWMC)	34.0
LLNL	3.5
LANL	> 1.0

NOTE: ICPP = Idaho Chemical Processing Plant; RWMC = Radioactive Waste Management Complex
Source: U.S. Department of Energy

The remainder of this section reviews the storage conditions for separated ^{233}U at the sites shown in Table 1.

3.1 OAK RIDGE NATIONAL LABORATORY (Radiochemical Development Facility, Building 3019)

The current mission of the Radiochemical Development Facility (RDF) is to serve as the national repository for ^{233}U in the possession of DOE's Office of Defense Programs. Building 3019 currently stores, distributes, and receives ^{233}U on an as-needed basis.

3.1.1 Storage Conditions

The RDF currently contains more than 1,100 "cans" (described below) of ^{233}U. More than 98 percent of these are in steel- and lead-lined storage wells, which are embedded in concrete. The remaining containers are currently stored in gloveboxes in various laboratory areas. More than 95 percent of the material is in oxide form. The remainder exists either as a metal or a salt (uranium tetrafluoride [UF_4]). There is a relatively small amount of ^{233}U remaining as a nitrate solution in a tank identified as P-24, which contains a total of 15,000 liters of solution (U.S. Department of Energy, December 1996).

The majority of the material is stored in four sets of top-loaded storage wells. One set contains 68 wells, each consisting of a carbon steel pipe 30 ft in length, embedded in concrete. The other three sets of storage wells (a total of 26 wells) are located in the massive walls separating several hot cells (these heavily shielded hot cells are no longer used, but contain contaminated processing equipment). Each such storage well consists of a stainless steel pipe 15 ft in length, embedded in concrete. All of the wells are vented to the vessel off-gas (VOG) system (Oak Ridge National Laboratory, October 10, 1996).

In general, after receipt for storage at the RDF, the material to be inserted in the storage wells was packaged in screw-lid or welded-lid primary containers. These containers, which were sometimes in plastic bags, were removed from gloveboxes and placed in food-pack cans (i.e., cans with a crimped metal lid) as secondary containers. The screw-lid inner containers were made from a variety of materials, including stainless steel. The welded-lid containers were made of stainless steel or aluminum. The food-pack cans were made of aluminum or tin-plated stainless steel. The secondary containers for salt material were contaminated and, therefore, placed in plastic bags. These were not placed into food-pack cans, but inserted directly into the storage wells. No standard methodology was used for packaging the ^{233}U prior to storage.

The inventory of ^{233}U in the RDF is not in active use. Prior to a shipment of ^{233}U received from Mound this past summer, no ^{233}U-bearing material had been received for a decade. In addition, because of the radiation hazards, no stored cans had been inspected since 1991.

Some of the ^{233}U containers have been in storage for more than 30 years (see Table 2 for a recent time-in-storage distribution), and their exact condition is unknown. In 1991, six cans that had been in storage for only 8 years were visually inspected. No signs of degradation of the cans were evident. No further inspections have since been performed, and no material has been repackaged.

Table 2. Storage Time for Containers in the Storage Wells

Number of Years	Number of Containers
>25	186
20 to 25	21
15 to 20	66
10 to 15	170
5 to 10	641
<5	13

Another way of evaluating the inventory is by noting the amount of ^{232}U in the material in storage relative to the ^{233}U content (see Section 2). Table 3 shows that more than 40 percent of the inventory has greater than 50 ppm of ^{232}U, and thus the radiation fields associated with this material are significant (see Table 3 and Appendix C).

Table 3. Amount of ^{232}U Present in Stored ^{233}U

^{232}U (ppm)	^{233}U Mass (kg)
<5	3
5 to <10	176
10 to <50	72
>50	176
All	427

Seventeen containers of UF_4 were received from SRS and placed in storage in 1968. This material was separated and packaged in the period 1964–1965; it is about 60 weight percent uranium. RDF personnel have stated that only these 17 containers will potentially require material stabilization. The need for stabilization will be based on the results of a planned container inspection in fiscal year (FY) 1998. Treatment processes for this potential stabilization have yet to be identified. However, only bulk metal and uranium oxides (preferably uranium yellow cake [U_3O_8]) are believed to be suitable forms for long-term storage. If the UF_4 is to be placed in long-term storage, the Board staff suggests that it would be advisable to consider converting it to oxide or metal. Additional details can be found in Appendix D.

RDF personnel have written a procedure for handling and storing ^{233}U (Oak Ridge National Laboratory, December 17, 1993). This procedure provides requirements for receipt, handling, and nuclear criticality safety, but it does not specify allowable forms, packaging requirements, or surveillance requirements. RDF personnel also developed specific criteria for acceptance of the ^{233}U from Mound for storage at the RDF, which was mentioned above. These criteria included requirements for the inner and outer cans, as well as for material characteristics and container ^{233}U loading. However, the use of plastic as bagging material in the containers was permitted. By analogy with the standard for storage of plutonium, this practice appears inappropriate, since the specific alpha activity for ^{233}U with potentially hundreds of ppm of ^{232}U approaches that of weapons-grade plutonium. In addition, the maximum allowable ^{233}U loadings appear to have been derived from nuclear criticality safety concerns and not from concerns about possible pressurization of the containers.

3.1.2 Storage Well Ventilation

Each of the storage wells has a ventilation exhaust header attached to the VOG system. This is a high-vacuum, low-flow system; the primary flow path is out the east side of Building 3019 via several ventilation lines, followed by a tie-in into the main header at ground level. This route through the main header provides a bypass through the 3121 Filter Building, where final flow is underground to the Building 3039 stack; here the gas passes through scrubbers prior to going through roughing and high-efficiency particulate air (HEPA) filters. A survey of the Building 3039 stack filter that was performed years ago, but not documented, disclosed nanocurie quantities of cesium-137 and strontium-90 on the filter. There have been instances of leakage from the VOG ductwork welds and flanges outside Building 3019. The resulting contamination was determined to be from ^{232}U, ^{233}U, and their daughters. This duct holdup material is suspected of having come from the previous Consolidated Edison Uranium Solidification Project (CEUSP) campaign, not from the storage wells.

A branch of the VOG system ties into the cell off-gas (COG) system. The COG system is a low-vacuum, high-flow system for exhausting air from the VOG system upon a loss of function of the stack exhaust fans of Building 3039. Airflow in the COG system is through roughing and HEPA filters before release through the Building 3020 stack. The COG system piping upstream of the 3091 filter house was sealed (patched and painted) about 2 years ago; previously, contamination leaks from the COG ductwork had been fairly common.

In 1983, contamination was detected in two storage wells during a radiation survey of open storage wells. The packages in the contaminated well have been in storage for more than 25 years. RDF personnel believe that this contamination was the result of a breach of a contaminated outer plastic bag enclosing a can containing ^{233}U salt and not a leak of the sealed container. The conjecture is that if a container had been leaking, the radiation levels would have been much higher. It is believed this contamination migrated to a second adjacent storage well since a much lower level of contamination was detected there. This migration is thought to have taken place through the VOG exhaust piping for the second storage well, and it could have occurred as a result of insufficient air flow. The exhaust piping of the VOG system is the only direct path between the storage wells when the wells are closed. There is no evidence that contamination has migrated outside of the wells or farther into the exhaust piping of the VOG system as a result of this occurrence. However, when the wells are opened, radiation surveys are not routinely performed.

More recently, contamination was identified outside Building 3019 on flanges of the facility's ventilation system. The flanges have been sealed with a fiberglass coating and are monitored on a periodic basis. No attempt has been made to characterize the contamination or to identify the source. Currently there appears to be no transferable surface contamination or detectable alpha contamination, and beta-gamma surface readings are not increasing.

The RDF was built during the Manhattan Project (1944). The recent HEU vulnerability assessment (U.S. Department of Energy, December 1996) identified it as one of the 10 most vulnerable facilities in the complex. The assessment also found that the most significant vulnerability at ORNL was associated with the potential failure of cans containing ^{233}U oxide either in static storage in wells or during inspection, handling, and repackaging in Building 3019.

3.2 IDAHO NATIONAL ENGINEERING LABORATORY (INEL)

^{233}U at INEL consists predominantly of fuel elements, some irradiated and some unirradiated. In this section, the unirradiated material is discussed; Section 4 provides a short discussion of irradiated fuel issues.

3.2.1 Idaho Chemical Processing Plant (ICPP)

The CPP-749 facility at ICPP is designed to provide dry, beneath-grade storage for irradiated and unirradiated fuels. The irradiated fuel containing ^{233}U in CPP-749 is discussed in Section 4. The unirradiated fuel stored in CPP-749 is all from the Light Water Breeder Reactor (LWBR) program. The material consists largely of fabricated fuel elements (of various designs) stored in stable arrays within shipping canisters, located in 22 vaults within CPP-749 (U.S. Department of Energy, March 1989). Although the vaults were designed to remain dry, small amounts of water have been detected during biennial inspections (Idaho National Engineering Laboratory, November 12-14, 1996). If larger amounts of water were to be encountered, as has occurred in the past with an earlier vault design, corrosion of the storage canisters could become a concern.

3.2.2 Radioactive Waste Management Complex (RWMC)

Radioactive and transuranic wastes at INEL are managed in the RWMC. Approximately 215 drums of waste containing significant amounts of ^{233}U are stored in three separate facilities within the RWMC: the Intermediate Level Transuranic Storage Facility (ILTSF), the Air Supported Building (ASBII), and the Transuranic Storage Area (TSA) (Idaho National Engineering Laboratory, November 12-14, 1996). Another 1,650 or so drums contain contaminated equipment and waste. The contamination includes ^{233}U, but ^{233}U is not the primary isotope of concern. The ^{233}U is contained in uranium dioxide (UO_2) ceramic fuel pellets, both loose and in fuel rods, that came from the LWBR program. These fuel components were shipped to RWMC from the Bettis Atomic Power Laboratory between 1974 and 1980 (Lockheed Idaho Technologies Company, October 28, 1996). The amounts of ^{233}U in each of these facilities are provided below, along with a general description of the particular facility.

The ILTSF contains asphalt pads on which several categories of waste are stored. The facility stores 53 drums of ^{233}U-bearing material. The ^{233}U-bearing waste in the ILTSF is stored in 6M shipping containers (110-gallon drums), which are contained within larger rectangular

metal shipping boxes, 6 drums to a box. These boxes are, in turn, stored inside the three original trailers that brought the material to RWMC. The three trailers are ringed by a concrete block wall for shielding purposes (contact radiation readings on the trailers are as high as 200 mrem/h) (Idaho National Engineering Laboratory, November 12-14, 1996). Because of both the shielding material and the position inside the trailers, the drums are not presently inspectable; visual inspection of the outside of the trailers has revealed no significant corrosion or other degradation.

Table 4. INEL Unirradiated Fuel Storage Summary

Facility	^{233}U Containers	^{233}U Mass (kg)	Condition Comments
Intermediate Level Transuranic Storage Facility (ILTSF)	53 drums	14.8	Drums inside transport container; not easily inspectable.
Air Supported Building II (ASBII)	12 drums	1.7	Drums recently segregated and inspected; no significant degradation.
Transuranic Storage Area (TSA)	150 drums	17.5	Drums under earthen cover; indeterminate status.
CPP-749	22 vaults	317.0	Sealed storage canisters within steel-lined vaults; some moisture detected during inspections.

Source: Idaho National Engineering Laboratory, November 12-14, 1996.

ASBII, as indicated by the name, is an air supported building structure with an asphalt floor. Drummed waste is stored in arrays that are stacked 5 drums high. Until recently, the 12 ^{233}U-bearing 6M drums stored in ASBII were commingled with other waste drums in one large drum array. In mid-November 1996, these ^{233}U drums were located and segregated. Although there was some light surface corrosion on the drums, no significant degradation was apparent (Idaho National Engineering Laboratory, November 12-14, 1996). The radiation readings at the surface of the drums were as high as 250 mrem/h.

The remaining 150 drums of ^{233}U material are under earthen cover within the TSA. Consequently, they cannot be inspected for degradation. However, during recent retrievals from the TSA facility, other drums were found to be substantially degraded (see Appendix G for more detail) (Idaho National Engineering Laboratory, November 12-14, 1996). As a result, the drums containing ^{233}U present a potential concern for loss of geometry control, both from the standpoint of criticality safety and for loss of radiological containment. Present plans at the RWMC are to

start retrieving materials from the TSA starting in the year 2003, and to repackage them for shipment to the Waste Isolation Pilot Plant (U.S. Department of Energy, February 1996). It is not clear that this strategy provides adequate control for the ^{233}U stored in this facility.

3.3 LOS ALAMOS NATIONAL LABORATORY (LANL)

^{233}U is currently stored in the Chemistry and Metallurgy Research (CMR) Building, the Los Alamos Critical Experiments Facility (LACEF) (Technical Area 18 [TA-18]), and the Plutonium Facility (TA-55). In general, ^{233}U processing and handling have not occurred for a number of years. During the HEU vulnerability assessment (U.S. Department of Energy, December 1996), it was found that a significant number of containers holding ^{233}U at LANL have internal packaging of unknown composition. Subsequent review by the Board staff indicated that greater than 25 percent of the ^{233}U containers at LANL either had unknown packaging materials or were known to have been packaged in plastic. Pressurization of a container can be caused by the buildup of radiolysis products, chemical reaction, or changes in temperature. Since the internal packaging is unknown, pressurization could result in the breach of a container that has deteriorated (Los Alamos National Laboratory, October 28, 1994).

3.3.1 Chemistry and Metallurgy Research (CMR) Building

LANL personnel stated that there are 46 ^{233}U items currently in storage in the CMR Building. The material can be broadly divided into two groups. The first group includes 31 items stored in the hot cells in Wing 9. Of these 31 items, 28 are sealed metal tubes, each 8 inches long by .5 inch in diameter; the form of the material is suspected to be oxide. Another item is a sealed metal disk 2 inches in diameter by .25 inch thick, in which the form of the ^{233}U is suspected to be metal. There are also 2 additional items suspected to be ^{233}U metal originally packaged in direct contact with plastic. Over time, the plastic has changed to a grainy black tar-like residue that cannot be separated from the metal. These 2 items were originally placed in a lead pig for shielding some time ago. The pig is highly contaminated. The items are currently stored in a nitrogen atmosphere, packaged in a can, plastic bag, and can combination. LANL personnel have inspected all 31 of these items in anticipation of off-site shipment. The 2 metal items had interacted with the surrounding plastic. LANL has performed preliminary cleanup; however, they may require processing prior to shipment or interim storage.

The second group consists of 15 items, 3 of which are metal, 5 oxide, 5 process residues, and 2 solution. Except for the 2 solution items, these materials are packaged in the can, plastic bag, can configuration.

3.3.2 Los Alamos Critical Experiments Facility (LACEF) (TA-18)

TA-18 has a total of 40 ^{233}U items (17 metal and 23 oxide). In general, the material has been in storage for at least 10 years since the last time critical experiments were performed using ^{233}U. This was probably the last time the containers were opened. The material has been at TA-18 for at least 20 years. LANL personnel anticipate performing additional critical experiments with this material. This program includes plans to process the ^{233}U to remove the highly radioactive daughters (including the daughters of ^{232}U). However, funding limitations are presently an obstacle. The material is generally stored in slip-lid containers and stainless steel pipes, which are then placed into lead pigs to reduce the gamma dose to workers. LANL personnel stated that they are not sure of the packaging configuration inside these containers. For example, these items may have been packaged directly into plastic—a practice inferred from the 2 similar metal items in storage at the CMR Building. In addition, LANL personnel are not sure of the geometry of the stored material, i.e., pressed or loose oxide and foils or bulk metal. From a facility perspective, TA-18's Hillside Vault exhaust stack has no HEPA filters. A fire or earthquake could release ^{233}U in the vault, which could spread unfiltered to the outside environment (U.S. Department of Energy, December 1996).

3.3.3 Plutonium Facility (TA-55)

There are 81 ^{233}U items in storage at the Plutonium Facility. Most are categorized as high-purity product materials, such as metal (about 43 percent) and dioxide (23 percent). Several items may contain machining turnings. Also in storage are 2 items containing ^{233}U-contaminated combustible cellulose rags. In addition, there are about 10 items that contain process residues, such as carbide, nitrate, and fluoride compounds, and sulfate solutions (Los Alamos National Laboratory, October 28, 1994).

LANL personnel believe that much of the ^{233}U oxide is contained in small welded stainless steel pipes placed in lead containers to attenuate the gamma radiation. However, some of the residue items are in the common can, plastic bag, can packaging configuration.

3.4 LAWRENCE LIVERMORE NATIONAL LABORATORY (LLNL)

The inventory of ^{233}U at LLNL includes 47 items with a total mass of about 3.5 kg (U.S. Department of Energy, June 27, 1996). The 47 items include metal, alloy, compounds such as oxides, and process residues. This material is stored in lead-lined pigs in the main vault of Building 332. Historically, this material was used for weapons test tracer sets, but it has now been declared excess to mission needs. LLNL is actively trying to identify a receiver site for this material. LLNL has not processed ^{233}U for more than 8 years.

LLNL is unable to provide a more detailed breakdown for each of the four broad categories of items discussed above. They have stated that a characterization program for the

^{233}U items (which would include records research and examination of items as necessary) was planned to begin in 1995, but was never accomplished.

Most of the material was packaged in welded tracer bodies. However, some was packaged in poly bottles, which were then overpacked in a crimp-sealed foodpack can. In some cases, three crimp-sealed cans were used. These containers were then placed in lead containers to attenuate the gamma flux.

4. STATUS OF URANIUM-233 IN SPENT FUEL

4.1 OAK RIDGE NATIONAL LABORATORY (ORNL)

The Molten Salt Reactor Experiment (MSRE) at ORNL was shut down in 1969. The fuel for this reactor was a combination of uranium (fissile materials in the form of ^{233}U and ^{235}U) in fluorides of lithium, zirconium, and beryllium. The unique makeup of this material leads to numerous additional hazards over and above those normally associated with ^{233}U.

Approximately 4,650 kg of these salts, containing about 31 kg of ^{233}U, is in two storage tanks. In 1987, abnormal radiation levels (5 roentgens[R]/h) were detected in a room adjacent to the fuel drain tanks. Part of the annual surveillance and maintenance program was an annealing or reheat of the salt mixture with the intent of recombining the fluorine generated by radiolysis of the fuel salt. The annual annealing was suspended after 1989 because it was suspected to be responsible for the increase in radiation. Subsequent investigations finally concluded that significant quantities of reactive gases (uranium hexafluoride [UF_6] and fluorine [F_2]) are present in the piping, and approximately 2.6 kg of uranium migrated from the fuel drain tanks by gas transfer to the auxiliary charcoal bed (ACB).

The fuel drain tanks and the fuel flush tank are made of the nickel base alloy HASTELLOY Alloy N. No quantification of the room temperature corrosion rate of HASTELLOY Alloy N has been available, except the conclusion that it is small. There is an apparent in-leakage of moist air into the system that could affect the corrosion of the HASTELLOY Alloy N tanks, and increase the potential for stress corrosion cracking in the stainless steel off-gas system. No effort has been made to determine whether the stainless steel components are cracked, and no effort has been made to identify the source of the moist air.

The uranium contains about 160 ppm of ^{232}U. As discussed in Section 2, the presence of ^{232}U and ^{233}U creates very high radiation fields. The neutron activity of the salts from (α,n) reactions is much greater than normal because of the presence of elements that have appreciable cross-sections for this reaction at the energies available from uranium decay.

In addition, important chemical reactions are occurring in the system. Very reactive fluorine gas is present at nearly 0.5 atmosphere (atm). Hydrogen fluoride (HF) gas, which is very corrosive if it condenses, has been detected in the piping. This indicates that water has entered the system in spite of the design intent that it remain dry. Furthermore, fluorine gas reacts readily with charcoal. This reaction could become very energetic, leading to a possible fire, if a criticality or other incident raised the temperature above 300°C. Additional detail can be found in Appendix E.

4.2 IDAHO NATIONAL ENGINEERING LABORATORY (INEL)

At INEL, the irradiated fuel that contains ^{233}U is stored in two dry storage facilities. One, an outdoor facility (CPP-749) is described above. The other, the Irradiated Fuel Storage Facility (IFSF), provides shielded, internal storage for irradiated fuel in a structure that is collocated with one of the wet storage basins (CPP-603). This irradiated fuel is presently the subject of planning and corrective actions in support of DOE's spent fuel vulnerability assessment (U.S. Department of Energy, November 1993). The irradiated ^{233}U fuel is mentioned in this report for the sake of completeness.

4.2.1 CPP-749

Two varieties of irradiated fuel are stored in this facility. First, the irradiated fuel from the LWBR program, discussed above, is stored here. The fuel assemblies, which contain 514 kg of ^{233}U, are in 50 vaults. Fuel from the Peach Bottom-1 nuclear power plant is also stored in CPP-749. This fuel was shipped to INEL between 1968 and 1977 (Idaho National Engineering Laboratory, November 12-14, 1996). As shown below, this fuel is not as rich in ^{233}U. In fact, it contains only about 20 kg of this isotope.

4.2.2 Irradiated Fuel Storage Facility (IFSF)

The remainder of the fuel from the Peach Bottom nuclear power station (with about 26 kg ^{233}U content) is stored in this facility, as is ^{233}U-bearing fuel from the Fort St. Vrain nuclear power station. The Fort St. Vrain fuel was shipped to INEL between 1980 and 1991. This material contains a higher concentration of ^{233}U than that in the Peach Bottom fuel, as shown in Table 5.

Table 5. ^{233}U in Irradiated Fuel

Facility	Mass ^{233}U (kg)	Total U Mass (kg)	Fuel Source
CPP-749	514.3	550.5	LWBR
CPP-749	20.6	206.5	Peach Bottom
IFSF	25.8	125.6	Peach Bottom
IFSF	90.1	308.3	Fort St. Vrain
Totals	650.8	1,190.9	

Source: Idaho National Engineering Laboratory, November 12–14, 1996.

4.3 SAVANNAH RIVER SITE (SRS)

^{233}U is present in irradiated thorium- and uranium-oxide fuel at SRS. This material (approximately 30 kg) is contained primarily in ^{233}U fuel from the Dresden and Elk River reactors. This fuel is stored in the Receiving Basin for Offsite Fuel. Also stored in the reactor basins are 17 Mark 50A ^{232}Th target slugs that contain ^{233}U (U.S. Department of Energy, November 1993).

5. CONCLUSIONS

It is understood that work is presently ongoing within DOE to address some of the concerns raised by the presence of ^{233}U at the various facilities. However, efforts to deal with DOE's remaining ^{233}U inventory would be greatly enhanced by a more systematic and focused approach, which might include the following considerations:

- *Establishing clear line-management responsibility for this material, and providing the necessary authority and resources to resolve the safety issues associated with ^{233}U.* Responsibility for this material is not clearly defined and is spread throughout DOE (Defense Programs [DP], Environmental Management [EM], Energy Research [ER], and Fissile Material Disposition [MD]). Being a material without a mission or requirement, for which responsibilities within DOE are fragmented and unclear, it has significant potential to become a "legacy" material.

- *Identifying the ^{233}U technical expertise remaining in the complex and establishing a "lead laboratory/lead site" for the development of a comprehensive plan to characterize, repackage, process, and transport ^{233}U and place it into long-term storage.* Issues associated with this material are presently being dealt with in a fragmented manner through various corrective action plans, including the Implementation Plan for Board Recommendation 94-1. A single, comprehensive, and integrated plan, developed and executed by the complex's ^{233}U technical experts, has the potential to deal more effectively and efficiently with the unique issues associated with ^{233}U.

- *Adequately characterizing the storage of ^{233}U in the nuclear weapons complex.* At various facilities throughout the complex, there exists material that is known to contain ^{233}U, but there are many uncertain issues, such as its mass, chemical form, and packaging. These uncertainties could potentially result in container corrosion and/or pressurization; unplanned radiation exposure; contamination; and, if quantities were sufficient, an inadvertent criticality. Therefore, materials need to be appropriately characterized before processing and/or repackaging plans are formulated. Issues also exist with the facilities within which ^{233}U is stored. This review need not be a major research and development or analytical effort, but rather a simple accessing of the material to determine important parameters such as form, geometry, packaging material present, and ^{232}U content. This information is necessary in order to determine the need for further processing. Information regarding facilities is necessary to assess their adequacy for long-term use.

- *Developing DOE-wide specific packaging; transportation; and transient, interim, and long-term storage standards for ^{233}U, and subsequently implementing those standards.* These standards would consider the above-discussed hazards and related

issues, and ensure that ^{233}U activities are performed safely. Consideration might be given to assessing the applicability and subsequent tailoring of plutonium standards for use as ^{233}U standards. Implementation of the standards may require processing and stabilization of the materials in some cases.

APPENDIX A. URANIUM HAZARDS

Some of the principal uranium hazards of concern are pyrophoricity and container pressurization. These are discussed briefly below.

A.1 PYROPHORICITY

Finely divided uranium metal is pyrophoric, but massive pieces of uranium will not burn unless they are exposed to a severe, prolonged fire. Small pieces of uranium metal can be safely stored in water or oil as long as the container is vented. Uranium metal chips and turnings oxidize readily in air and often spark when they are handled dry. They can ignite spontaneously in a container—especially if water vapor is present. Uranium does not burn in the "normal" manner, but undergoes solid-state combustion. No flames are present, but the glowing metal can reach very high temperatures. Burning is similar to that of thermite (magnesium).

Large pieces of uranium metal react with moisture in air until an oxide layer forms on the surface and inhibits further oxidation. Small pieces of uranium metal with a higher surface area can react with moisture rapidly enough to exceed the venting capability of a container and allow hydrogen gas to accumulate in the headspace. If an ignition source is present, it can ignite the hydrogen and cause a deflagration. Either uranium metal contacting the drum wall or the spontaneous ignition of pyrophoric materials can provide such an ignition source.

A.2 CONTAINER PRESSURIZATION

Container pressurization can occur if a relatively large amount of water vapor contacts uranium metal in a container with little void volume. This situation usually occurs only if some moisture is trapped in a primary container at the time the container is sealed. Most of the hydrogen produced from moist air leaking into the primary container will probably leak out through the same opening, with little pressurization of the container. Venting of containers with adequately sized and functioning carbon composite filters is one method of preventing container pressurization.

Radiolysis of organics by ^{235}U and ^{238}U is relatively insignificant because of their low specific activities. The half-lives of ^{235}U and ^{238}U are so long (7×10^8 and 4×10^9 years, respectively) that most of the activity in HEU comes from ^{234}U, which has a half-life of 2×10^5 years, although it makes up only a small fraction of the uranium. In addition, ^{235}U and ^{238}U emit few gamma rays and have low spontaneous fission rates.

APPENDIX B. FORMATION OF URANIUM-232 AND URANIUM-233

B.1 URANIUM-232

^{232}U is a by-product of the irradiation of ^{232}Th, ^{235}U, and ^{230}Th, if present. The amount of ^{232}U in the ^{233}U ranges from several ppm to more than 100 ppm. ^{232}U is formed primarily via four sets of nuclear reactions.

The first and predominant path includes an (n,2n) reaction with ^{232}Th (natural thorium) to produce ^{231}Th. ^{231}Th subsequently decays (half-life of 25 h) by beta emission to protactinium-231 (^{231}Pa). ^{231}Pa undergoes neutron capture to form ^{232}Pa, which decays (half-life of 1.3 days) by beta emission to ^{232}U.

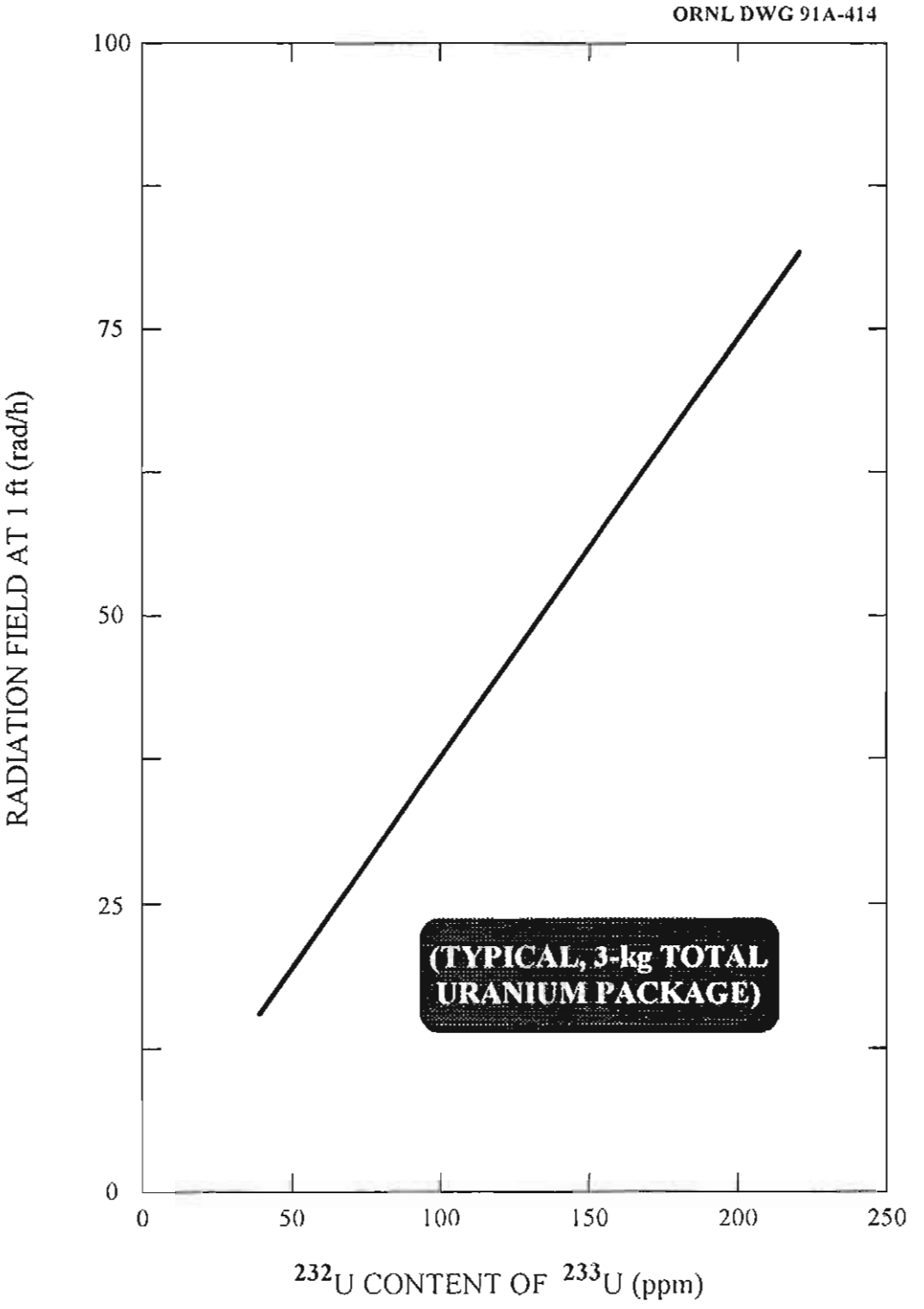
The second path is an (n,2n) reaction with ^{233}U. If ^{235}U is used as the fissile material in a fuel, a third path is the production of ^{237}U from two successive neutron captures in ^{235}U. The ^{237}U subsequently decays (half-life of 6.7 days) by beta emission to neptunium-237 (^{237}Np). ^{237}Np then undergoes an (n,2n) reaction to form ^{236}Np, which decays (half-life of 22 hours) by beta emission to plutonium-236 (^{236}Pu). ^{236}Pu then decays (half-life of 2.85 years) by alpha emission to ^{232}U.

A fourth path exists if some ^{230}Th was present in the thorium ore, which is obtained as a by-product of uranium mining. ^{230}Th is a radioactive decay product of ^{238}U. ^{230}Th then undergoes neutron capture to ^{231}Th. The rest of the pathway is identical to the first path.

B.2 URANIUM-233

^{233}U is formed by neutron capture in ^{232}Th to yield ^{233}Th, followed by beta decay (half-life of 22 minutes) to ^{233}Pa, followed by a second beta decay (half-life of 27 days) to ^{233}U.

APPENDIX C. RADIATION FIELDS ASSOCIATED WITH URANIUM-232 CONTENT



APPENDIX D. DETAILS OF MATERIAL STORED IN BUILDING 3019

The largest mass of ^{233}U from a single batch of material is in 403 containers from the Consolidated Edison Uranium Solidification Project (CEUSP). The project was completed in 1986, and the material was then packaged and stored in the wells. This material is in oxide form and contains about 62 weight percent uranium. During the processing of this oxide, the material was heated to about 700°C. This oxide is primarily U_3O_8, with much smaller amounts of uranium trioxide (UO_3) and UO_2. Another 27 containers of non-CEUSP material were prepared using the same process.

The next-largest batch of ^{233}U is in 206 containers. This material was separated and packaged between 1980 and 1988. The material is primarily U_3O_8. During processing, it was heated to about 800°C.

The batch containing the largest number of individual items (1743) is unirradiated Zero Power Reactor fuel plates. Each plate is 3 inches long by 2 inches wide by 0.25 inch thick and contains ^{233}U in the form of U_3O_8 clad with stainless steel. These plates were manufactured by RDF personnel in the late 1970s and placed into the storage wells in 1988.

The largest batch of UO_3 is in 134 containers. This batch was received from SRS and placed into storage in the mid-1960s. The largest batch of UO_2 is in 44 containers. This material was separated and packaged in 1976 and placed into the storage wells in 1985.

RDF storage records indicate that the bulk of the metal in storage consists of large pieces (0.5 to 1.0 inch). However, there are some metal foils in storage. For long-term storage, it is generally acknowledged that metals need to have a specific surface area of less than 1 cm^2/g to eliminate pyrophoricity. The foils in storage may approach this limit, depending on their dimensions.

APPENDIX E. MOLTEN SALT REACTOR EXPERIMENT ISSUES

The auxiliary charcoal bed (ACB), part of the off-gas treatment system, consists of two U-tube charcoal traps, which are fabricated from 6 inch diameter stainless steel pipe with a total length of approximately 80 ft. The ACB is located in a 10 ft diameter, 24 ft deep underground concrete pit. The ACB pit was filled with water to cool the charcoal traps and provide shielding during reactor operation. The ACB pit remained full of water until recently, such that the charcoal traps were fully submerged when the uranium was discovered to be located in the ACB. That water was subsequently drained from the pit.

It is estimated that about 2.6 kg of ^{233}U has been deposited in the ACB, while another 5.8 to 6.0 kg exists as a gas in other sections of the off-gas system, as well as the head space of the two fuel drain tanks and flush tank. The single parameter mass limit for a uniform aqueous solution of ^{233}U is about 550 grams (g). However, the deposits of ^{233}U are very undermoderated. For a solid piece of water-reflected ^{233}U metal, the single parameter mass limit is 6.0 kg.

In the North Electric Service Area (where the high radiation levels were first detected), the specific locations of ^{233}U present in the off-gas system lines have not been completely established. As stated previously, a deposit outside of the fuel drain tanks and the ACB could be as large as 6 kg of ^{233}U. In addition, the critical mass of ^{233}U in the presence of water decreases from that required for dry $^{233}UF_6$, and criticality may become a concern. Criticality in these circumstances is not an incredible event.

E.1 METALLURGICAL ISSUES

As noted in Section 4, the fuel drain tanks and the fuel flush tank are made of the nickel base alloy HASTELLOY Alloy N. The off-gas system and the charcoal bed filter vessel are made of type 304 stainless steel. The components were assembled by welding without any post-weld annealing to relieve stresses.

Analysis of vapor in the off-gas system line from the fuel drain tanks showed 10 millimeters (mm) mercury (Hg) pressure of molybdenum hexafluoride (MoF_6). The presence of MoF_6 is an indication that the HASTELLOY Alloy N is under attack at room temperature. The analysis also showed the presence of nitrogen and HF in the off-gas vapor. These results indicate that moist air is leaking into the system. The off-gas lines would be expected to be immune to corrosion by fluorine gas and UF_6 at room temperature. However, the presence of moisture and HF in the off-gas system creates the potential for stress corrosion cracking.

In spite of the apparent corrosive attack on HASTELLOY Alloy N, no quantification of the room temperature reaction rate has been made, except to say that it is small. No attempt has been

made to determine if the stainless steel components are cracked, and no attempt has been made to identify the source of moist air.

E.2 CHEMICAL AND RADIOLOGICAL ISSUES

The circulating fuel solution was a mixture of lithium and beryllium fluorides containing uranium fluoride as the fuel and zirconium fluoride as a chemical stabilizer. The initial fuel charge was highly enriched ^{235}U, which was later replaced with ^{233}U. Small amounts of plutonium fluoride were added to the ^{233}U to gain experience with plutonium in a molten salt reactor. Following reactor shutdown, the fuel salt was drained into two storage tanks. The flush salt, which contained 1 to 2 percent of the uranium and fission products, was drained into a third tank. The salts were allowed to cool to room temperature and solidify. Including the uranium that has migrated, the fuel salt and flush salt contain about 37 kg of uranium and 740 g of plutonium. Approximately 87 percent of the uranium and 90 percent of the plutonium are fissile. The salts also contain more than 27,000 curies (Ci) of fission products, predominantly ^{90}Sr and ^{137}Cs.

Radiolysis of the fluorine salts by gamma rays produces fluorine radicals, which can recombine with the salt or form fluorine gas. For many years, the salt was annealed annually to 350°–500°F, but not melted, to promote the recombination of the fluorine radicals. As discussed previously, this practice was suspended after 1989 when DOE began to suspect that the annealings were increasing radiation levels in nearby off-gas system lines. DOE suspects that fluorine radicals in the salt lattice reacted with the UF_4 to form UF_6. The high temperatures of the annealings may have allowed the UF_6 to sublime and enter the head space above the salt in the tank. The UF_6 could then have been carried by the out-gas flow through a 0.5 inch off-gas system line until it reached the ACB. There the UF_6 was reduced by the charcoal to UF_4. ORNL personnel believe that uranium migration occurred only during the annealings. This is because normal temperatures are not expected to drive the UF_6 from the salt and through the narrow pipe. This is supported by high-accuracy radiological monitoring of the piping in the North Electric Service Area, which has not shown any increase in radiation levels (Defense Nuclear Facilities Safety Board, February 14, 1995).

APPENDIX F. VULNERABILITIES ASSOCIATED WITH URANIUM-233 FROM THE HIGHLY ENRICHED URANIUM VULNERABILITY ASSESSMENT

Site	Location	Identifier	Description
ORNL	Building 3019	SAT-001	Failure of storage well containers due to aging and corrosion.
ORNL	Building 3019	SAT-002	Earthquake- and wind-caused failures of building and equipment, with releases.
ORNL	Building 3019	SAT-003	Leakage of Tank P-24 solutions during transfer operations.
ORNL	Building 3019	SAT-004	Failure to evaluate Tank P-24 for resistance to earthquakes, tornados, or missiles.
ORNL	Building 3019	WGAT-001	Potential corrosion, gas generation, and failure of ^{233}U oxide, which can cause worker exposure during inspection and repackaging.
ORNL	Multiple	SAT-001	Failure to evaluate seismic and wind resistance of facility structures.
INEL	RWMC	WGAT-003	Incompatible storage of more than 200 drums of ^{233}U and thousands of transuranic waste drums in the RWMC, creating hazards for workers.
INEL	RWMC	WGAT-004	Poor storage practices and drum corrosion, causing releases of HEU material and worker contamination.
INEL	RWMC-ILTSF	SAT-006	Loss of integrity of 53 drums containing ^{233}U currently in cargo containers in an open yard, resulting in nuclear criticality.
INEL	RWMC-TSA	SAT-007	Corrosion and loss of structural integrity and designed spacing of drums containing ^{233}U, resulting in a nuclear criticality accident.
LANL	Multiple	SAT-005	Unknown internal HEU packaging material resulting in increased exposure to workers.
LANL	TA-18	WGAT-002	Lack of air filtration from the Hillside Vault.
SRS	235-F	WGAT-001	Corrosion of HEU shipping containers resulting from leaky vault roof.
SRS	235-F	SAT-001	HEU with ^{233}U and collocated/commingled plutonium in plastic or unknown packaging.

Source: U.S. Department of Energy, (December 1996)

APPENDIX G. TRANSURANIC (TRU) WASTE STORAGE AT IDAHO NATIONAL ENGINEERING LABORATORY (INEL)

INEL has been storing TRU waste on its property since 1954. Between 1954 and 1970, the waste was disposed of under earthen cover in the Transuranic Disposal Area (TDA) at the Radioactive Waste Management Complex (RWMC). In 1970, the Atomic Energy Commission (AEC) directed that interim storage of TRU must be accomplished in an above-ground, retrievable containment area. As a result of this directive, two asphalt-covered pads, known as Transuranic Storage Areas (TSAs)-1 and -2, were constructed.

The TSA-1 pad area (about 100,000 ft^2) is divided into eight cells providing TRU waste storage for various containers, including steel drums, steel boxes, and plywood boxes, designed to meet the 20-year interim storage criteria. These cells, once filled, were covered with plywood sheeting, a layer of 0.5 mm polyethylene, and 24 inches of soil to resist water intrusion. The TSA-2 pad area, similar in design to TSA-1, is partitioned into two cells of approximately 15,000 ft^2 each. The drums and boxes stored at the TDA were buried under several feet of soil, with no additional measures taken to prevent intrusion of the elements.

In the late 1970s it was decided that penetration of these storage areas—and container retrieval, if necessary—should be performed to determine the extent of any cell, drum, or box degradation. Other objectives of the proposed action were to sample the soil in the TDA for leakage or migration of waste, and provide drums to Rocky Flats for a characterization and categorization study. Data were to be obtained to assist in determining whether the waste containers could maintain integrity over the required 20-year period.

During August 1978, an initial penetration was made into Cells 1 and 6 of TSA-1 to retrieve 102 drums—70 drums from Cell 1 and 32 from Cell 6. Cell 1, which contained horizontally stacked drums and plywood boxes, had closed in May 1971. Cell 6, closed in November 1973, contained vertically stacked 55-gallon drums and fiber-glassed plywood boxes. All of the retrieved containers were visually inspected for any signs of damage or deterioration— including rust, corrosion, breaching, bulging, or labeling indicating unanticipated hazardous material—before being placed in temporary storage until further visual and mechanical inspections could be performed. The entire retrieval operation was accomplished without compromising the integrity of any of the waste containers.

Of the 70 drums recovered from Cell 1, only 2 showed significant signs of rust and corrosion, both on drums from the bottom row whose sides had been contacting the asphalt pad. These 2 drums also appeared to have failed gaskets from either a material defect or mishandling while stacking. All other drums showed little degradation other than occasional small, thin layers of rust, primarily on the unpainted lockrings. The plywood boxes in Cell 1 also appeared to be relatively well preserved.

The fiberglass-coated boxes surveyed in Cell 6 showed no visible signs of deterioration. Of the 32 drums removed from the cell, most seemed to be in good condition, although several of the vertically stacked drums had free rust on the lids, lockrings, and/or bottom rings.

It can be assumed that among the reasons the drums retrieved from Cell 1 were generally in superior condition to those recovered from Cell 6 is the fact that they were stacked horizontally to minimize the area of flat surfaces, where moisture tends to collect, and that they were painted with a black bituminous-based paint vice a white alkylyd paint.

An additional 70 drums were retrieved from TSA-1 and TSA-2 in October/November 1979. Ten drums were removed from each of 7 cells—numbers 2, 3, 4, 5, 7, and 8 of pad TSA-1 and Cell 1 of pad TSA-2. The objectives of the TDA penetration and sampling activities performed in September/October 1979 were to retrieve the oldest stored drums for assessment and to sample the soil in the immediate area of the buried containers. Ultimately, in situ ultrasonic testing was accomplished as the degraded condition of the waste containers precluded removal.

The overall condition of the TSA-1 and TSA-2 cells and waste containers appeared to be very good, with little evidence of structural degradation. The only exception noted was with Cell 5 of TSA-1, where the plywood sheeting had inexplicably been placed on *top* of the poly lining, exposing it directly to the soil and elements. The plywood had severely decomposed, and moisture had intruded onto the poly liner, as well as the lids of the waste drums. The 10 drums retrieved from Cell 5 had freestanding water on the lids and excessive corrosion on the lockrings as compared with rust found on drums removed from other cells. As described in more detail later, this particular cell would be penetrated again 5 years later to remove, sample, and repackage deteriorated waste containers.

The horizontally stacked drums exposed during overburden removal at the TDA exhibited varying degrees of corrosion. One drum was breached during removal of soil cover, and subsequently resealed and taped. Because of the advanced state of environmentally precipitated decomposition or mechanically induced damage to the plywood boxes and drums, retrieval of these waste containers was not practical. Although none of the waste containers were breached to the extent that contamination had spread, dents, scratches, and signs of rust were evident on lids, lockrings, and bodies of drums.

Waste storage container retrieval from Cell 5 of TSA-1 was reinitiated in July 1984 and completed in November 1984. The intent was to remove damaged boxes and drums first documented during the 1979 cell penetration, and to repair, overpack, or repackage as appropriate to ensure safe long-term storage, as well as to sample some of the waste containers. Surveys performed in the area of Cell 5 prior to soil removal showed no indication of surface contamination.

A total of 240 plywood boxes were removed from Cell 5. Most of the boxes were in relatively good condition, with the exception of several that had suffered structural damage during either overburden removal, stacking of drums, or water intrusion. Boxes that had been breached or damaged were overpacked in cargo containers and stored in auxiliary support buildings.

Generally, all but a few of the steel drums retrieved from Cell 5 were in good to excellent condition. A number of the drums were bulging and had to be vented, while 1 had been breached and was overpacked into an 83-gallon drum. In all, 2509 drums were reclaimed from Cell 5 and moved to interim storage.

In summary, a total of 2681 steel drums and 240 plywood boxes were removed from the storage/disposal areas. Of those totals, about 20 of the drums were damaged to some extent—mostly from corrosion—and about 5 of the plywood boxes had deteriorated primarily because of water intrusion. These data are presented in Table G-1.

Table G-1. Idaho National Engineering Laboratory—TRU Waste Retrieval and Inspection					
Site Location[1]	**Closure/ Burial Date**	**Penetration/ Removal Date**	**Quantity & Type(s) of Containers Removed**	**Damaged Containers**	**Comments**
TSA-1 (Cell 1)	May 1971	August 1978	70 horizontally stacked 55-gallon drums	2 corroded drums	Corroded drums were from bottom row; plywood boxes in cell were well preserved
TSA-1 (Cell 6)	November 1973	August 1978	32 vertically stacked 55-gallon drums	Several lightly corroded drums	Drums had free rust on body or lockrings; fiberglass-coated boxes in cell were in good shape
TSA-1 (Cells 2,3,4 7,8)	December 1971 - October 1975	October/November 1979	50 drums (10 drums from each cell)	None	Drums were in very good condition
TSA-1 (Cell 5)	June 1973	October/November 1979	10 drums	all 10 drums removed showed signs of corrosion	Plywood covering was decomposed; excessive lockring corrosion; freestanding water on lids
TSA-2 (Cell 1)	December 1977	October/November 1979	10 drums	None	Drums were in very good condition
TDA	1970	September/October 1979	None removed; retrieval not practical	Most containers exposed during overburden removal	Dents, scratches, rust on drums; plywood boxes were decomposed
TSA-1 (Cell 5)	June 1973	July-November 1984	240 plywood boxes; 2509 drums	Several boxes with structural damage; few steel drums	Boxes were damaged during overburden removal, stacking, or water intrusion; bulging and corroded drums
			Total Number of Containers Removed: 2681 steel drums 240 plywood boxes	**Total Number of Damaged Containers: ~20 steel drums ~5 boxes**	

Notes: 1. INEL site TRU waste storage locations include Transuranic Storage Areas (TSAs)-1 and -2 and the Transuranic Disposal Area (TDA).

ACRONYMS AND ABBREVIATIONS

ACB	auxiliary charcoal bed
ASBII	Air Supported Building II
Board	Defense Nuclear Facilities Safety Board
CEUSP	Consolidated Edison Uranium Solidification Project
Ci	curie
CMR	Chemistry and Metallurgy Research
COG	cell off-gas
CPP	Chemical Processing Plant
DOE	Department of Energy
F_2	fluorine
FY	fiscal year
g	gram(s)
HEPA	high-efficiency particulate air
HEU	highly enriched uranium
HF	hydrogen fluoride
Hg	mercury
ICPP	Idaho Chemical Processing Plant
IFSF	Irradiated Fuel Storage Facility
ILTSF	Intermediate Level Transuranic Storage Facility
INEL	Idaho National Engineering Laboratory
kg	kilogram(s)
LANL	Los Alamos National Laboratory
LACEF	Los Alamos Critical Experiments Facility
LLNL	Lawrence Livermore National Laboratory
LWBR	Light Water Breeder Reactor
MeV	million electron volts
MoF_6	molybdenum hexafluoride
MSRE	Molten Salt Reactor Experiment
ORNL	Oak Ridge National Laboratory
ppm	parts per million
rem/h	rem per hour
RDF	Radiochemical Development Facility
RWMC	Radioactive Waste Management Complex
SRS	Savannah River Site
TA-18	Technical Area-18 (Los Alamos Critical Experiments Facility)
TA-55	Technical Area-55 (Plutonium Facility)
TSA	Transuranic Storage Area
U	uranium
UF	uranium fluoride
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride

ACRONYMS AND ABBREVIATIONS (concluded)

UO	uranium oxide
UO_2	uranium dioxide
UO_3	uranium trioxide
U_3O_8	uranium yellow cake
VOG	vessel off-gas

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