Description of document:	Two (2) Defense Nuclear Facilities Safety Board (DNFSB) Technical reports regarding storage of radioactive materials, 1996, 1997
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Document Titles:	Technical Report No.8 (DNFSB/TECH-8): Uranium and Thorium Storage Safety at Major Department of Energy Facilities, May 1996 Technical Report No.18 (DNFSB/TECH-18): Review of the Safety of Storing Plutonium Pits at the Pantex Plant, November 25, 1997
Source of document:	FOIA Request Information/FOIA Officer Defense Nuclear Facilities Safety Board 625 Indiana Avenue NW, Suite 700 Washington, DC 20004 Email: FOIA@dnfsb.gov (ATTN: Information Officer)

From: Katherine Herrera
Date: Mar 29, 2016 3:10:07 PM
Subject: FOIA 16-07 - Final Response

RE: Freedom of Information Act Request (FOIA # FY 16-07).

This email is in response to your FOIA request (FY 16-07) dated February 14, 2016, and received in the Board's FOIA Office on February 16, 2016. On March 7, 2016, we invoked a 10-workday extension to respond to your request. We have now completed your request, the results of which are outlined below.

* The Board located one 48-page record responsive to your request for Board Technical Report 8, which is being released to you in part. Portions of Technical Report 8 have been withheld under FOIA Exemption 6, which applies to "personnel and medical files and similar files the disclosure of which would constitute a clearly unwarranted invasion of personal privacy." 5 U.S.C. § 552(b)(6). The phrase "similar files" covers any agency records containing information about a particular individual that can be identified as applying to that individual. See United States Dep't of State v. Washington Post Co., 456 U.S. 595, 602 (1982). To determine whether releasing records containing information about a particular individual would constitute a clearly unwarranted invasion of personal privacy, we are required to balance the privacy interest that would be affected by disclosure against any public interest in the information. See United States Dep't of Justice v. Reporters Comm. for Freedom of Press, 489 U.S. 749, 773-75 (1989). The information that has been withheld under Exemption 6 consists of the names of low-level Board employees who work in a national security field involving nuclear engineering and nuclear weapons. See Long v. OPM, 692 F. 3d 185 (2nd Cir. 2012) (holding that the names of federal employees in five sensitive agencies and twenty-four sensitive occupations [including nuclear engineering in the national security context] were properly withheld because disclosing the names could subject them to risk of harassment or attack). We have determined that the individuals to whom this information pertains have a substantial privacy interest in withholding it. Additionally, you have not provided information that explains a relevant public interest under the FOIA in the disclosure of this personal information and we have determined that the disclosure of this information would shed little or no light on the performance of the Board's statutory duties. Because the harm to personal privacy is greater than whatever public interest may be served by disclosure, release of the information would constitute a clearly unwarranted invasion of the privacy of these individuals. Accordingly, we are withholding the names under Exemption 6.

Please note that portions of Technical Report 8 could be withheld pursuant to Exemption 5's deliberative process privilege, because this record was a draft document containing some internal deliberations. However, I have determined in this instance that such material may be disclosed to you as a matter of agency discretion.

*	The Board located one 30-page record responsive to your request for Board Technical Report 18, which is being released to you in part. For the same reasons articulated above, however, the names of low-level Board employees contained in Technical Report 18 have been withheld under Exemption 6.

*	Finally, after a thorough search, we have determined that records responsive to your request for Technical Report 11 no longer exist.

Based on the above information, this constitutes a partial denial of your request. Accordingly, you have the right to appeal this determination to the Board’s General Counsel. If you choose to do so, your appeal must be received within 30 calendar days of the partial denial determination. For your reference, the Board’s appeal procedures can be found at 10 C.F.R. § 1703.109.Your request is now completed, and we have waived all fees associated with this request. If you have any questions, please do not hesitate to contact me via phone at 202-694-7000, toll free at 800-788-4016. Please provide your assigned Board tracking number (FY 16-07) in any future communications with our office regarding your request.

v/r,
Katherine R. Herrera
FOIA Officer

DNFSB/TECH-8

Uranium and Thorium Storage Safety
at
Major Department of Energy Facilities

Defense Nuclear Facilities Safety Board

Technical Report

May 1996

Uranium and Thorium Storage Safety
at
Major Department of Energy Facilities

This paper was prepared for the Defense Nuclear Facilities Safety Board by the following staff members:

b(6) [redacted]

PREFACE

This report documents reviews by Defense Nuclear Facilities Safety Board staff of uranium and thorium storage safety at major Department of Energy facilities. These reviews were initiated in 1994 and have continued into this year. Most of the work here was completed and discussed with Department of Energy in late 1994.

In the past year, the following issues have been addressed:

- The potentially pyrophoric uranium metal chips and turnings stored in unvented drums inside Building 883 at the Rocky Flats Environmental Technology Site have been repacked into vented drums and mixed with inert material. Additional drums of similar material have recently been found inside Building 444.

- The Y-12 Plant uranium standard was issued in May 1995. The final criteria address the Board's interest in the interim storage of pyrophoric uranium.

The following issues remain unresolved:

- The Fernald Environmental Management Project continues to store drums of uranium metal chips, turnings, and saw fines that are potentially pyrophoric. Testing could resolve whether this is actually the case.

- The unvented drums of wet uranium saw fines at the Y-12 Plant are awaiting shipment to the Nevada Test Site.

- No effort has been made to convert ^{233}U at the Oak Ridge National Laboratory to forms more suitable for long-term storage or to determine the condition of their containers. Container inspections are still scheduled for 1998.

- Container corrosion and breaches continue to occur, especially at sites such as the Fernald Environmental Management Project where they are stored outside.

May 1996

Uranium and Thorium Storage Safety
at
Major Department of Energy Facilities

CONTENTS

CONTENTS
(continued)

I. INTRODUCTION

This report examines the safety of stored uranium and thorium at several sites in the Department of Energy (DOE) complex. It covers natural uranium (which contains 99.3 percent ^{238}U and 0.7 percent ^{235}U) and uranium enriched or depleted in ^{235}U and ^{233}U. The physical forms of uranium and thorium considered are metals; compounds; solutions; and scrap materials, which are mixtures of uranium or thorium with other substances. Uranium or thorium ores and tailings, which are the residues from processing of ores, are not considered. Uranium or thorium contained in high-level waste, mixed with plutonium, or in the form of hexafluoride (the gaseous compound used in isotopic enrichment facilities) is also excluded.

The primary sites that store ^{235}U in various enrichments are the Oak Ridge Y-12 Plant (Y-12), the Fernald Environmental Management Project (FEMP), the Savannah River Site (SRS), the Rocky Flats Environmental Technology Site (RFETS), and the Idaho National Engineering Laboratory (INEL). The uranium and thorium inventories of these sites are summarized in Table 1. The total uranium inventory in the DOE complex is approximately 500,000 metric tons (MT), of which 88 percent is depleted, 9 percent is natural, 2 percent is low-enriched (defined as containing between 0.7 and 20 percent ^{235}U), and less than 1 percent is highly enriched [1]. All but about 33,000 MT of the depleted uranium (DU) is in the form of UF_6, and is thus excluded from this report.

Table 1. Masses of Uranium and Thorium at Five DOE Sites (Metric Tons)

Site	Material				
	Depleted Uranium	**Natural Uranium**	**Low-Enriched Uranium**	**Highly Enriched Uranium [2]***	**Thorium**
FEMP	4,000	450	2,200	0	930
INEL	3,000	< 1	0	26	0
RFETS	340	0	< 1	7	< 1
SRS	22,000	35	99	24	< 1
Y-12	classified	< 1	classified	169	classified

* Inventory on December 31, 1993.

With the exception of Y-12, most of the uranium facilities have been shut down. Y-12 is the primary DOE site for the recovery, processing, formation, and machining of highly enriched uranium (HEU). As of early 1995, some processes were operational, while others were shut down for safety reasons or lack of feed streams. Until it was shut down in

July 1989, FEMP produced uranium metal from a variety of feed materials [3]. At SRS, HEU and DU fuel rods were fabricated, irradiated, and reprocessed to recover uranium and plutonium. The Idaho Chemical Processing Plant (ICPP) recovered HEU from research, test, and naval reactor fuels for use as fuel in the SRS reactors [4]. RFETS manufactured enriched and DU weapon components and removed plutonium contamination from returned enriched uranium components.

A significant amount of the separated ^{233}U in the DOE complex is stored at the Oak Ridge National Laboratory (ORNL) in Building 3019, the Radiochemical Development Facility (RDF). Other sites with kilogram quantities of separated ^{233}U include the Los Alamos National Laboratory (LANL), the Lawrence Livermore National Laboratory (LLNL), and the Mound Site. The sites storing significant amounts of unseparated ^{233}U, found as irradiated thorium fuel or ^{233}U fuel, are INEL, ORNL (at the Molten Salt Reactor Experiment), and SRS.

The remainder of this document is organized as follows. Chapter II addresses general issues associated with uranium and thorium storage. Chapter III presents a detailed description of the draft uranium storage standard issued by the Y-12 Plant. Next is a discussion of uranium and thorium storage conditions at five DOE facilities—Y-12, FEMP, SRS, INEL, and RFETS. This is followed in Chapter V by a review of the general status of ^{233}U at four sites in the DOE complex. Finally, Chapter VI presents conclusions of the study. Two appendices are also provided: Appendix A, which summarizes uranium and thorium hazards, and Appendix B, which describes the formation of ^{232}U and ^{233}U. The report ends with a list of references and a glossary of acronyms.

II. GENERAL ISSUES OF URANIUM AND THORIUM STORAGE

This section summarizes general storage issues for the DOE sites examined, including standards for uranium storage, the stability of uranium in storage, and container integrity. Details describing the situation at specific sites are presented in Chapter IV.

A. Standards for Uranium Storage

Nongovernmental (e.g., American Nuclear Society) standards, DOE standards, and DOE Orders that apply to uranium and thorium storage usually address criticality and security issues, or are only indirectly applicable to the safe storage of the materials (e.g., DOE Order 5480.23, *Nuclear Safety Analysis Reports*) [5]. There are no formal DOE standards describing which forms of uranium and types of containment are acceptable for interim and long-term storage. DOE Order 6430.1A, *General Design Criteria*, provides requirements for unirradiated enriched uranium storage facilities [6]. Although most of these are structural requirements for the facility, there are some general guidelines for confinement systems. The primary confinement (i.e., cladding or storage container) must be corrosion resistant and prevent uncontrolled releases. Compartments and their ventilation systems must have positive seals to prevent the migration of contamination.

In August 1993, a Uranium Storage Assessment Team was formed to develop a DOE-wide uranium storage standard. This team produced two reports: *Assessment of Uranium Storage Safety Issues at DOE Facilities* [7] and the draft *Criteria for the Storage of Uranium Metal and Uranium Compounds* [5]. In August 1994, DOE decided to make the uranium storage standard specific to Y-12 because there are too many forms of uranium (i.e., isotopes, chemical compounds, enrichments) to include in one standard. DOE anticipates adapting the Y-12 standard to other sites. Y-12 has issued a draft assessment of enriched uranium storage safety issues [8] and draft criteria for the storage of HEU [9]. This latter standard is discussed in detail in Chapter III. While Defense Nuclear Facilities Safety Board (Board) staff believe this standard is beneficial, standards (preferably DOE standards) still need to be developed for uranium that is not highly enriched or is at sites other than Y-12.

None of the other sites examined has anything comparable to the draft Y-12 uranium standard. Each has some procedures dealing with uranium storage, but there are usually gaps in the coverage of issues addressed. FEMP has the most extensive set of procedures, addressing packaging, storage, movement, and inspection issues [10-16]. Storage requirements for thorium are practically nonexistent at all the sites.

Board staff believe that the criteria for long-term storage of plutonium are generally applicable to long-term storage of ^{233}U [17]. This is based on the fact that the specific alpha activity for ^{233}U with hundreds of parts per million (ppm) of ^{232}U approaches that for weapons-grade plutonium. The criteria for long-term storage of plutonium include requirements for acceptable material form, packaging, and inspection and surveillance of the material. For example, plutonium oxides are required by the standard to be thermally stabilized to less than 0.5 percent loss on ignition (LOI), where LOI is the percentage of mass loss when an oxide sample is heated to a specified temperature for a specified time (typically to 1000ºC for at least 1 hour). Another requirement is that no organic material be packaged with the plutonium metal or oxide. This restriction prevents the formation of hydrogen and other radiolysis product gases that could pressurize a sealed container or, in the case of hydrogen, possibly form pyrophoric plutonium hydrides as a result of hydrogen reacting with plutonium metal.

B. Stability of Uranium in Storage

Appendix A summarizes general uranium and thorium storage hazards.

Most HEU is stored as bulk pieces of metal or oxide. The bulk metal is not pyrophoric and is quite stable. Because uranium processing is ongoing, there are no large inventories of HEU residues that have been in storage for several years, as there are for plutonium. Most of the residues that exist are not mixed with reactive metals or other unstable material. Corrosion of HEU during long-term storage is possible if HEU metal is not stored in containers with an inert or dry atmosphere or in a humidity- and temperature-controlled facility. The resulting oxide surface layer can become airborne under unfavorable circumstances. However, the amount of corrosion that would occur in a sealed can as a result of trapped water vapor is not expected to produce enough hydrogen gas to pose a fire, explosion, or overpressurization hazard. Any hydrogen generated because of leakage of moist air into an unsealed can would probably leak out before accumulation would become a hazard [5].

DU is not stored as carefully as HEU because it has a low economic value and does not pose a criticality risk. Tens of thousands of drums of DU have been stored in warehouses or outside for many years. DU is also stored in a much wider variety of forms than HEU, including residues, feed streams, and intermediate products; these forms may contain contaminated solvents and free reactive metal. Small pieces of DU metal, which may be pyrophoric, are stored at RFETS and FEMP. Board staff observed that there was a higher chance of finding freestanding liquids in drums of DU metal than in containers of enriched uranium. The subsequent reactions between water and uranium metal can generate hydrogen gas and pyrophoric uranium hydride, resulting in drum explosions [18]. It is advisable that small pieces of metal be oxidized or melted into larger pieces for long-term storage, and placed in vented containers inside a storage building for interim storage. Unless pyrophoricity is a concern, the presence of water is to be avoided.

C. Container Integrity

Uranium containers are often stored in arrays that are not readily inspectable. It is very difficult to inspect the conditions of drums stored in close array or cans stored in modular storage vaults. Under such conditions, container corrosion and breaches are usually not discovered until the container is moved. Furthermore, many routine inspections of this material do not include examining the condition of the containers. Because radiation from depleted, natural, and enriched uranium is not penetrating, worker dose would not increase much if container surveillance were increased. These issues could be resolved by including visual examination of container conditions as part of routine inspections and by adding more aisles in closely packed arrays of drums. Although this would increase the amount of storage area required, it would also reduce the risk of handling breached drums.

Several storage practices for thorium, DU, and natural uranium often contribute to a high corrosion rate. As noted above, some drums are stored outside, and thus they are exposed to rain and wind. Some warehouses at FEMP and SRS have leaks that allow rain to enter or walls that allow water and mud to run in around the bottom of the drums and pallets. Drums containing chips or fines may have water in them. Most forms of the uranium and thorium, however, are oxide, bulk metal, or fluoride. If the breaching of a container of this material caused a significant amount of respirable-sized particles to become airborne, it could pose a risk to nearby workers. There is a high likelihood that this material will require periodic overpacking or repacking, especially if it is being moved, until disposition is complete.

III. THE DRAFT Y-12 PLANT URANIUM STORAGE STANDARD

This chapter summarizes the contents of the Y-12 uranium standard, which was still in draft form as of April 1995. Board staff are working with Y-12 personnel to resolve staff comments on the draft standard. The final versions of the uranium standard and formal acceptance criteria are scheduled for completion in mid-May 1995.

The Y-12 uranium standard will be applicable to long-term storage of uranium with an enrichment greater than 20 percent [9]. The actual length of time for which the standard is designed to provide for safe storage is not specified, but is assumed to be indefinite. Acceptable forms of uranium include metal, qualifying alloys, and oxide. Excluded from the formal acceptance criteria are irradiated uranium or uranium containing sufficiently high concentrations of ^{232}U, ^{233}U, ^{236}U, decay products, or transuranic elements to cause either radiation levels or criticality hazards significantly greater than those for HEU. Also excluded are canned subassemblies, in-use or in-process material, and low-equity material that can be discarded. Work on a standard for canned subassemblies is scheduled to begin after the HEU standard is finished.

The acceptable geometrical form for metal is a cast, right annular cylinder (4.445 cm inner radius, 6.35 cm outer radius). The preferred mass is 18 kg, with a maximum of 20 kg. The specific surface area of the metal must be less than 1 cm^2/g, and all loose surface oxide must be removed. All machine turnings, chips, saw fines, and other high specific surface area metal must be converted to forms that meet the storage criteria. The metal must also be packaged for storage in dry air or an inert atmosphere with a moisture content of 100 ppm or less. Inert atmospheres should be doped with 1.0 ± 0.5 percent oxygen to reduce corrosion by water vapor. Uranium alloys or intermetallics may be acceptable if their criticality safety, corrosion resistance, flammability, and health/environmental impacts are comparable or superior to those for pure uranium metal.

The acceptable form of oxide is U_3O_8, in the form of a loose powder. An exception may be granted for UO_2 and UO_3 if (1) the presence of ^{232}U, ^{233}U, or ^{236}U would cause unacceptable radiation exposure to workers or facilities during conversion to U_3O_8; (2) the material is not pyrophoric; and (3) the material has a moisture content low enough to prevent pressurization in the primary container greater than one atmosphere over the facility's lifetime.

The primary containment required by the Y-12 standard is a crimp-sealed 304-L stainless steel can. A low-carbon steel is used to reduce corrosion in the welded longitudinal seam of the can [8]. Plastics, oils, and other combustible materials are not allowed to be in contact with uranium metal, but plastic bags are permissible for U_3O_8 storage. Acceptable secondary containment includes tube vaults and modular storage vaults. Storage facilities will meet the requirements of the Fire Prevention Code and DOE Order 5480.7A, *Fire Protection* (except that fire sprinklers will be prohibited). Continuous monitoring of airborne radioactive particulate matter will be provided.

Uranium in interim storage (limited to 10 years or less) is supposed to be stored in Department of Transportation (DOT) Type A or Type B shipping containers. The standard allows any form of uranium to be in interim storage for up to 10 years; conversion of unsafe forms to forms acceptable for long-term storage is not required. Material in transient storage must meet Y-12 Plant acceptance criteria and be in DOT-approved shipping containers.

The development of a uranium standard at Y-12 is encouraging, but the current draft standard addresses only part of the larger issue of the lack of standards for storage of other forms of uranium. The standard is applicable only for long-term storage of HEU metal and oxide. Y-12, however, has 91 material form codes. The current interim storage requirements allow these other forms to be stored for up to 10 years, but do not provide any real guidance on how to store this material until it can be converted to metal or oxide or disposed of as waste. Although these other forms of uranium are more likely to be associated with potential safety issues than are the relatively stable bulk metal and oxide, there are no additional (in fact fewer) requirements for their storage. Furthermore, criteria for storage of DU (which poses the same chemical hazards as HEU) are not included in the standard and are left for future development. No mention is made of any future development of standards for low-enriched uranium (LEU) or natural uranium.

IV. URANIUM AND THORIUM STORAGE CONDITIONS AT FIVE DEPARTMENT OF ENERGY FACILITIES

This chapter reviews the uranium and thorium storage conditions at Y-12, FEMP, SRS, INEL, and RFETS.

A. Y-12 Plant

1. Inventory: Material stored at Y-12 includes DU, natural uranium (69 kg), LEU, and HEU, as well as thorium. (The amounts of these materials are classified.) The uranium and thorium inventory is divided into eight categories of material: alloyed metals, unalloyed metals, compounds, solutions, combustibles, noncombustibles, process residues, and multicategory material (e.g., filters and hold-up). Most of the HEU is stored as unalloyed metal. Much of the remaining HEU consists of compounds (e.g., UO_3, crucible oxide, U_3O_8, and UF_4) and alloyed metal (e.g., reactor fuel elements and molybdenum, aluminum, and titanium alloys). DU and natural uranium are found as metal, alloyed metal, oxide, and other compounds. The bulk of the DU is metal and is stored in massive pieces (i.e., derbies, slabs, and billets).

   Y-12 has been designated as DOE's interim storage location for HEU until a decision on the ultimate disposition of HEU is made and implemented [1]. The HEU inventory is divided into strategic weapons stockpile and surplus material. Surplus HEU pieces and weapon components are physically destroyed, either mechanically or chemically, and converted into either bulk metal or oxide for storage. The current HEU inventory is split evenly between material in interim storage and material awaiting storage or processing.

   Y-12 is also storing the HEU purchased by the United States from the Republic of Kazakhstan [19]. Most of the material contains some reprocessed uranium, as indicated by the presence of ^{236}U and ^{232}U, as well as extremely small amounts of plutonium. The material is stored in approximately 1300 stainless steel cans measuring either 13 or 18 cm in height and 12 cm in diameter. There are seven different forms of uranium material: HEU metal, uranium oxides ($UO_2/UO_3/U_3O_8$), uranium-beryllium (U-Be) alloy rods, uranium oxide (UO_2)-beryllium oxide (BeO) ceramic rods, uranium-beryllium alloy scrap, HEU-contaminated graphite chunks, and laboratory salvage (U-Be alloy). Shipment of this uranium to a commercial vendor is scheduled to begin in late May 1995.

   At Y-12, nonirradiated thorium reactor fuel elements are stored in shipping containers. Bulk pieces of thorium metal are stored in drums or on pallets. Various miscellaneous forms of thorium are also stored in drums and in cardboard and wooden boxes.

2. Storage Conditions: Eight facilities at Y-12 currently store HEU or process it for storage: Buildings 9204-2, 9204-2E (reclamation), 9204-4 (quality evaluation), 9206 (blending/sampling/canning), 9212 (special processing/casting/canning/recanning), 9215, 9720-5, and 9998. Building 9720-5 is a single-story warehouse that will be the principal storage location for HEU at the plant [1].

   HEU in Building 9720-5 is stored in tube vaults, modular storage vaults, an in-process storage vault, an overnight storage vault, the rack storage vault for small container storage (i.e., bird cages—metal structures with favorable geometries regarding nuclear criticality), and the fuel element storage vault [8]. Tube vaults are horizontal steel tubes 12 ft in length inside reinforced concrete walls. Each tube may contain up to ten 1-gallon stainless steel cans, each storing up to 20 kg of HEU. The crimp-sealed cans contain cast, right annular cylinders of metal, pieces of broken metal, or oxide stored in an argon atmosphere. Modular storage vaults are stacks of heavy concrete pallets that contain a matrix of holes for cans of HEU. These stainless steel cans may contain either metal or oxides in the form of powders and castings. The pallets are stacked up to four high. The modular storage vaults have desirable safeguard features, but their limited access makes them difficult to inspect. Some vaults (also called cages) are isolated rooms within material access areas that have been built using wire mesh screen panels and steel structural supports. Cages store drums and shipping containers holding HEU and LEU, which are frequently mixed with other materials. Weapon components are also stored in drums inside cages. The drums are often stacked several tiers high, in a close array that limits inspection. In addition, a few shipping containers filled with unirradiated fuel are stored in this building.

   One vault in Building 9212 consists of rows of metal boxes. Each box contains a tray that may hold up to 20 kg of loose uranium metal pieces. Uranium is also stored in cages and bird cages. Until a year ago, it was a standard practice in Building 9212 to package uranium metal in direct contact with plastic before placing it in steel or aluminum food-pack cans for storage in other buildings. The current practice is to place the uranium metal in stainless steel food-pack cans. As older items are returned to Building 9212 from other buildings, they are repackaged using the new practice. Solid residues are usually stored in drums, tin-plated carbon steel cans, or stainless steel cans. Uranium residue solutions are kept in plastic screw-top bottles with the lids kept loose to prevent their pressurization. Some of the residues (e.g., organics) have been in storage since before 1992 because the equipment needed to process them is not operational.

DU and natural uranium are stored in unvented drums, in wooden and metal boxes, and as billets covered with aluminum sleeves. The billets and a few dozen drums are currently being stored outside. DU oxide mixed with metal fines is stored in Building 9825-1, the Uranium Oxide Storage Vault. A high-efficiency particulate air (HEPA) filter ventilation system was used to prevent emissions of oxide dust during loading operations. No provisions for removing the DU powder are included in the vault design, and this will complicate the future removal of the oxide. Metal powder is no longer emptied into the vault, but is stored inside a nearby shed. Y-12 hopes to ship the drums to the Nevada Test Site (NTS) for disposal.

3. <u>Chemical Stability of Material</u>: There is negligible risk of pyrophoricity for much of the uranium and thorium metal at Y-12 because most of it is stored in shapes with low specific surface areas. In the past, however, uranium fires occurred frequently at Y-12 when metal was being machined because of the heat of machining and the high specific surface area of chips and fines. Now, metal chips and fines are kept in a pool of coolant during machining. After machining, chips are stored in drums under coolant until the drum is two-thirds full, at which time several gallons of water is added. Chips and turnings from machining of uranium metal and uranium alloys are then oxidized in air under controlled conditions. Personnel at Y-12 stated to Board staff that the last chip fire occurred in 1992. DU metal fines are mixed with oxide powder at a 1:10 ratio, placed in an unvented 55-gallon drum, and tumbled to homogenize the mixed material. At one time these drums were emptied into the Uranium Oxide Storage Vault, but they are now stored inside sheds. Although short-term storage of wet saw fines is a common practice, this practice is not suitable for longer periods of time because of the potential for DU metal fines to react with water in the drums. Either the metal saw fines need to be oxidized in air under controlled conditions (as chips and turnings are), or the drums need to be vented.

Hydrogen generation is a minor problem for most of the enriched uranium because little moisture is present, the uranium metal is not finely divided, and no other reactive metals are present. Some organic material may be present, however. In old packages in storage, there may be plastic bags around the stored material or inner package, but uranium's low specific activity should not cause much radiolysis of the plastic. In the past, newly fabricated enriched uranium weapon components were routinely coated with oil for corrosion protection, but that practice could pose a small fire hazard [8]. Argon gas is presently used to reduce corrosion of metal (which generates hydrogen) in cans, but it is not known whether the argon will leak out of the cans over time.

Because Y-12 personnel do not consider hydrogen generation to be a problem, none of the drums at Y-12 are vented with carbon composite filters. Some drums and shipping containers, however, have vent holes that are often taped over to prevent water intrusion.

Liquid and solid uranium residues are also stored, awaiting recovery operations. In the past, some of these uranium solutions have had problems with fuming degradation of organic solvents from continued exposure to concentrated acid. Since then, acid concentrations have been reduced, and the holdup of solvents with acid has been minimized. There have been no cases of solvent degradation by fuming since the mid-1980s, when a 1-liter bottle ruptured because its tightly closed lid prevented gas from escaping.

B. Fernald Environmental Management Project (FEMP)

1. Inventory: The FEMP uranium inventory, including only solid material with uranium concentrations above the economic discard limit, is about 6600 MT, of which 90 percent is separated material and the rest recoverable residues. Of the separated material, 67 percent is DU, 8 percent is natural uranium, and 25 percent is LEU. The forms of the separated material are metal (54 percent), UF_4 (33 percent), and UO_3 (13 percent). An additional 1600 MT of uranium is contained in over 11,000 MT of low-level radioactive waste (LLRW). The total volume of uranium product, residues, and LLRW is equivalent to 147,000 55-gallon drums; 42 percent is LLRW. An additional 97 MT of uranium is being stored as uranyl nitrate solution.

   Most of the uranium is stored in 55-gallon drums and 10-gallon cans. Metal fuel element cores are stored in Al-lined wooden boxes, and metal ingots (a casting product) and derbies (UF_4 and magnesium reaction product) are stored unpackaged on metal and wooden skids.

   There is 927 MT of thorium in the forms of thorium nitrate gel (containing 4.3 kg of ^{233}U), residues, metal, oxides, solutions, and other miscellaneous compositions stored at FEMP. All of this material is classified as LLRW.

2. Hydrogen Generation and Overpressurization: In 1989, two drums containing uranium metal ruptured violently while being moved, blowing their lids an estimated 80 ft into the air. In 1992, another drum (overpacked inside two other drums) containing uranium metal exploded during movement, blowing the outermost two lids 25 ft into the air. Fernald Environmental Restoration

Management Corporation (FERMCO) personnel believe that in both cases, a hydrolytic reaction occurred between uranium metal and freestanding water in the drum, producing hydrogen gas, and that hydrogen ignition was caused by a spark in the drum [20, 21]. Additional bulging drums were subsequently discovered.

In response to these incidents, special procedures were developed for venting and moving drums that may contain uranium metal and water. Safety nets are required for the movement of drums that may contain free reactive metal or biologically generated gases (e.g., CO_2 and CH_4). Process knowledge, rather than material characterization, was used to determine which material codes may contain uranium metal, reactive metal, or biologically generated gases. The drums requiring safety nets include over 2,000 that may contain magnesium metal that can react with water to form hydrogen. Venting these drums would eliminate the problem of hydrogen buildup.

If it is thoroughly implemented, drum venting should reduce the likelihood and impact of hydrogen explosions or overpressurization, but there appear to be some problems with implementation. During a tour, Board staff observed a bulging drum that was not vented. FERMCO personnel stated that this drum was not expected to contain uranium metal, reactive metal, or biological gas generators. The bulges were assumed to be due to overfilling or expansion from the freezing of water in the drum. FERMCO personnel also indicated there are many other similarly bulged drums that are overpacked, but not vented or covered with safety nets during movement. It is possible that the content descriptions of the containers are inaccurate. Board staff also found drums in storage labeled "Vented" that did not contain bung vents or obvious vent openings. Upon investigation by FERMCO personnel, some bung plugs were found to be loose, which could allow gas to escape; others were tight.

3. <u>Pyrophoric Materials</u>: Most of the uranium and thorium metal at FEMP is in large pieces, with low surface-area-to-mass ratios. FERMCO personnel have, however, identified 48 uranium drums that may contain fine material that is potentially pyrophoric, such as metal chips and turnings. Some of this uranium has been placed in vented drums and covered with water to prevent ignition and promote slow oxidation. This is only a short-term solution because the water may evaporate before all of the metal is oxidized. Furthermore, the reaction of uranium metal and water produces hydrogen that could react to form uranium hydride, which is also pyrophoric. It is advisable that the material in these drums be converted to oxide in air under controlled conditions.

4. Container Corrosion and Storage Conditions: Container degradation, especially for drums, is a significant problem at FEMP because containers have been stored outside without protection. FERMCO personnel stated that the median lifetime of containers stored outside is only 3 years because of the high humidity. Although FERMCO is trying to transfer containers (especially those containing material types considered more hazardous) into buildings, approximately 23,000 drums are still stored outside, often with little or no protection from the rain. Uranium metal is stored outside under shelters, but these often consist of only a metal roof and minimal siding that could allow precipitation to fall on the containers. Furthermore, there are leaks in the roof of Plant 6 that can allow rain to fall directly on the drums and materials below. The presence of leaks is a concern because bare uranium metal ingots and skulls are also stored in the same building.

   Inspections are conducted to detect drums with corrosion, leaks, and bulges. A significant fraction of the drums (approximately two-thirds of the drums in Plant 1, the principal storage area) has been overpacked because of primary container degradation. Containers are often stacked in rows three to four drums high and four across. This arrangement prevents interior drums from being adequately examined.

   Preparations are being made to overpack approximately 5600 drums of thorium hydroxide, oxide, and oxalate stored in Building 65 and ship them to NTS for burial. These drums date from the 1970s and early 1980s and are in such poor condition that there is significant airborne contamination in the building. As a result, workers there are required to wear respirators. The reason for the severe corrosion is that the drums were stored on plywood sheets rather than pallets. This allowed rain, which came in through holes in the roof and windows (repairs were not funded for 8 years), to pool and collect around the drums. The Preliminary Safety Analysis Report estimates that up to 1400 drums may have been breached. Despite possible airborne contamination inside the building, normal glass windows are used to contain the airborne radioactive material. Concrete shields surround three sides of the building to reduce radiation levels outside, which are approximately 10 mrem/h without shielding.

5. Future Storage and Disposition: The large volume of uranium material and waste at FEMP has resulted in containers being stored in the old plants, warehouses, aluminum huts, tension support buildings, and shelters, as well as outdoors. Few of these locations were designed as storage areas, and they are often used for other activities. This results in a large population of personnel working near the drums, increasing the potential for unnecessary radiation exposure, contamination spread, and accidental movement of drums into unauthorized configurations. Access has already been limited in some areas

because of criticality spacing violations in 1993 and 1994. To correct this situation, FERMCO has been trying to consolidate its inventory into buildings designed for storage, including tension support buildings.

FERMCO has also been trying to reduce the inventory of uranium by shipment of low-level and mixed waste off site, by Department of Defense transfers of DU for shielding, and by private industry sales. The inventory has been reduced from 61 million lb in 1991 to 43 million lb today, predominantly as a result of shipping over 2,000 drum equivalents of LLRW per week to NTS. FERMCO is also disposing of some mixed waste with Envirocare in Utah and shipping Toxic Substances Control Act (TSCA) waste (e.g., contaminated polychlorinated biphenyl and asbestos) to the ORNL TSCA incinerator. Possible disposition activities that will require guidance from DOE include making shipments to other DOE sites (e.g., Y-12) and classifying much of the uranium as either LLRW or product excess to government needs. Without more off-site shipments or construction of new storage facilities, storage space shortages could cause delays in future decommissioning activities because such activities increase the amount of waste generated and reduce the available storage area.

C. Savannah River Site (SRS)

SRS's uranium inventory consists of over 22,000 MT of DU, 35 MT of natural uranium, and 99 MT of LEU. On December 31, 1993, 24 MT of HEU was also on site. This material is located primarily in M-, F-, and H-Areas. In addition, 178 kg of thorium is stored in various locations.

Most of the M-Area inventory is stored in two warehouses. The Finished DU Slug Product Warehouse (330-M) stores 1300 MT of DU in the form of aluminum-clad nickel-plated metal cylinders, which are in cardboard boxes on wooden pallets. The Bare DU Core Storage Warehouse (331-M) stores 1700 MT of unclad DU metal cylinders and bare natural uranium slugs in steel-lined wooden crates and boxes. All of this uranium will be stored indefinitely in the warehouses except for the natural uranium, which may be sold to a private company. An additional 25 MT of DU is contained in 650,000 gallons of mixed waste sludge that is mostly filter cake. The Vendor Treatment Facility, which is scheduled to begin operation in FY1996, will melt the sludge into glass, achieving a volume reduction of up to 80 percent. Building 321-M stores enriched uranium aluminum alloys. Al-clad tubes and assemblies are stored in borated concrete storage racks, while ingots are kept in lag storage and shipping drums. These materials are to be shipped to Y-12 by 1996. Building 321-M also contains U-Al alloy floor sweepings and casting waste products stored in drums and cans. Scrap material that can be recycled may be melted on site. Finally, DU and LEU mixed waste (filter cake and filter paper) is stored in metal boxes and drums at the Resource Conservation and Recovery Act (RCRA) facility. None of the containers in M-Area are vented. There have been no leaks, spills, or accidents involving uranium in M-Area.

F- and H-Areas contain tanks of uranyl nitrate hexahydrate (UNH) solution. In F-Area, 65,300 gallons of depleted UNH solution is stored inside Building 221-F and in outside facility tanks. There are also several tanks inside H-Canyon and in H-Area outside facility tanks (A-Line) that contain about 73,000 gallons of dissolved HEU fuel from research reactors and an HEU product from the second uranium cycle.

Nearly 20,000 MT of depleted UO_3 is stored in almost 36,000 unvented 55-gallon drums in F-, G-, and R-Areas. These drums are stored in very close arrays in metal warehouses; the drums throughout these warehouses are stacked three high, leaving an aisle around the outside only. Inspections are conducted quarterly for obvious leaks on the outside facing drums. Roughly half of the drums and warehouses date from the early 1950s, with the other half having been built in the mid-1980s. In the older buildings, water has been able to enter from roof leaks, broken windows, and surface runoff (there is a gap between the floor and the metal wall). Muddy inflows have covered the floor and the bottoms of drums. The drums have noticeable amounts of corrosion, and the drum stacks were observed to be leaning where the floor or the drums had weakened. Since May 1993, drums from R-Area are being overpacked and then transferred to F-Area. These old drums often have pinhole leaks and low levels of contamination. Although the drums may be breached, this represents mainly a contamination control issue and poses no serious risk to the workers.

There has been no evidence of overpressurization in the oxide drums that have been handled or that can be inspected. Although uranium metal is found in some locations, it is not found as finely divided pieces, but as bulk material. The Environmental Impact Statement for Interim Management of Nuclear Materials identifies the uranium feedstocks, fabricated forms, unirradiated fuels, DU solutions, and DU oxide as stable material. The preferred option for these materials is continued storage with active management. Only the HEU solutions and irradiated fuels and targets are classified as unstable. There is some concern with the HEU solutions because they are not stored in geometrically favorable tanks. Criticality safety is maintained by limiting the uraniun concentration, periodically sampling the solution, and monitoring the tank level. The solution in above-ground tanks (A-Line) is in the process of being transferred to a double-walled tank designed to withstand design basis natural phenomena events.

D. Idaho National Engineering Laboratory (INEL)

On December 31, 1993, INEL possessed 26.2 MT of HEU. The present inventory at the ICPP consists of UO_3 product from the ICPP denitration process, unirradiated fuel, graphite powders containing HEU oxide from LANL, U_3O_8 from RFETS, and scrap material from Argonne National Laboratory-West (ANL-W).

The largest category, denitrator product, consists of small, granular, irradiated UO_3 pieces stored in metal cans inside polyethylene sleeves, polyethylene bottles, and steel drums. This irradiated material may have significant radiation levels (i.e., 300 mrem/h on contact) from ^{232}U daughter products. Unirradiated denitrator product is stored in polyethylene bottles. The graphite powders contain 2 to 3 weight percent HEU, present as a fine oxide. This powder is stored in polyethylene bottles inside slip-lid metal overpack cans sealed with tape. ICPP personnel stated that they have not seen any degradation or pressurization in the plastic bottles. Some uranium metal is present in the ANL-W material, but it consists of chunks of metal with relatively low surface areas. Some of this material was originally packaged in an argon atmosphere that prevented formation of an oxide layer. In the early 1980s, there were two uranium metal fires that occurred when fines produced during sawing of the ANL-W disks spontaneously ignited. To prevent this from recurring, the uranium metal is now packaged in an air atmosphere to allow an oxide layer to form. The fuels in storage are kept in cabinets and boxes that contain cadmium, a neutron poison. Although none of the material is stored in vented containers, ICPP personnel stated that there have been no instances of bulging cans or drums, nor are there any major corrosion problems with the containers.

Nearly all of the ICPP enriched uranium inventory is stored in ICPP-651, the Unirradiated Fuel Storage Facility (UFSF), which is currently only 34 percent full. The cans are stored in racks that maintain geometrically favorable positions with regard to nuclear criticality. There have been two minor technical standard storage violations: one in which the positions of two cans were reversed and one in which uranium oxide was stored in glass rather than polyethylene bottles. Cans with high radiation levels are going to be stored in a new remotely operated storage system in which columns of cans sink below the shielded floor. Most of the fabrication scrap material and graphite powder in the UFSF is to be shipped to Y-12 or Babcock and Wilcox (B&W) by 1996.

INEL also stores depleted and natural uranium. At B&W's Specific Manufacturing Capability Project (a Department of Defense facility), there is approximately 3000 MT of DU metal. These large plates of metal are used to make tank armor. An additional 675 kg of DU and 128 kg of natural uranium are stored in various locations at the ICPP, ANL-W, and Test Area North.

E. Rocky Flats Environmental Technology Site (RFETS)

The uranium inventory at RFETS consists of LEU, HEU (6.7 MT on December 31, 1993), and 336 MT of DU. No natural uranium is stored on the site. The thorium inventory is very small: a 1 kg standard stored in a 10-gallon container in a vault and 20 minor sources.

The RFETS Health and Safety Practices Manual has a few requirements for storage of metal chips and fines. Except for these requirements, there are no on-site storage procedures for either enriched uranium or DU. There are procedures for off-site shipments, however. In the past, there have been workstation fires due to pyrophoric chips and fines. The only safety incident in recent history was a lid that blew off a 55-gallon drum while an employee was removing the lid. This occurred in Building 865 in 1989.

1. <u>Enriched Uranium</u>: More than 4,000 items of enriched uranium consist of metal, oxides, solutions, residues, and holdup. Metal pits are stored in 30-gallon containers formerly used for shipping. These containers are not sealed and provide no containment. Approximately one-half of the pits are scheduled to be shipped to LANL by 1998, with the remainder to be stored in Building 371 or possibly shipped to the Pantex Plant. Hemishells are packaged in plastic wrap and are to be shipped to Y-12. Some hemishells are contaminated with plutonium. In the past, these contaminated items were cleaned using a spray and leach process, but an electrolytic decontamination process is under development to reduce the amount of waste generated. Metal composites are wrapped in foil and plastic. Some are stored in 10-gallon stainless steel containers. None of the metal is considered pyrophoric; all chips and fines have been oxidized.

   Much of the oxide is enriched to only 4.5 percent; it was formerly used in nuclear criticality experiments. This oxide is stored in plastic wrap inside aluminum cubes or in shipping containers. This material is to be shipped to Y-12. The remaining oxide is bagged and stored in metal cans; some of it is mixed with plutonium oxide at various ratios.

   Approximately 2600 liters of high-purity UNH solution, containing up to 370 g/l of ^{235}U, is stored in eight stainless steel tanks [22]. The solution contains in excess of 560 kg of ^{235}U. The solutions will be included as part of the implementation of Board Recommendation 94-1. Although there are many uranium residue items, the total mass of enriched uranium is low. Most of the uranium residues are stored in 55-gallon drums, some of which are vented. Typical residues include incinerator ash, metal, filters, and standards. None of the residues contains hazardous chemicals. Some enriched uranium may also exist as holdup in parts of Buildings 881, 883, and 777.

2. Depleted Uranium: The DU is split evenly between oxides (mostly U_3O_8) and metal. DU metal is found as pure uranium metal (60 percent), DU (6 percent) Nb (30 percent), miscellaneous alloys (8 percent), and composites (2 percent). The primary storage locations for DU are Buildings 444/448, 883, and 664.

A uranium chip roaster in Building 444/448 has not been operated for the past 1½ years. There is 84.5 MT of large metal pieces stored on metal shelves, wood pallets, and skids, and 16.4 MT of oxides stored in 30-gallon drums overpacked with 55-gallon drums. An additional 1.4 MT of oxide is packed in sealed 30-gallon drums that have been awaiting overpacking for approximately 18 months. DU is also stored inside Building 664 and outside the building in cargo containers. This area contains 202 drums of low-level waste oxide and 317 drums of material suspected to contain low-level mixed waste. RFETS has shipped over 100 MT of uranium metal to other DOE sites in the last year and plans to ship much of the oxide material to NTS.

Building 883 contains 84 MT of metal. Large pieces are stored on shelving, pallets, and skids. Scrap pieces are stored in drums. An additional 8 MT of oxide from equipment holdup is stored in 30 drums. There are 20 drums containing DU machining chip turnings, saw filings, and composite residue sludges that are of special concern. The contents of these 20 drums are shown in Table 2.

Table 2. Contents of Depleted Uranium Drums in Building 883

Number of Drums	Drum Contents
1	Saw fines and water
1	Small chips and water
2	Dry chips
3	Sludge and water
4	Sludge, chips, and water
4	Dried sludge and chips
5	Dry sludge or “yellow-green material”

The sludge is a mixture of uranium oxides, machine turnings, saw filings, and machining coolants. In drums with water present, some or all of the material may be submerged. The chips and sludge are often described as having a yellow-green color, which implies that their surfaces have oxidized. All of the material is between 1 and 2 years old. Each of these 20 drums contains an inner drum and liner. The inner drum has a lid, and the outer drum is clamped and has a mechanical seal. The inner drums contain material varying in depth from 1 inch to entirely filled.

Although RFETS personnel stated they have had no safety problems with the drums, there are several potential safety issues. Uranium saw fines and chip turnings are potentially pyrophoric. In addition, the high specific surface areas of saw fines and chips increase the reaction rate of uranium with water, generating hydrogen gas. During a tour of Building 883, RFETS personnel opened a full drum of chip turnings and a drum containing submerged saw fines. Although the tightly fitting lids of the drums could allow buildup of hydrogen gas generated by uranium metal/water reactions, no safety precautions were taken to prevent sparking. The chip turnings showed small amounts of oxidation, and no sparking of the chips was observed. RFETS personnel stated, however, that the turnings could spark if spread out.

The drums themselves are in poor condition. The outsides of the old drums are corroded, scratched, and dented. For many years the drums have been used repeatedly to store material for the chip roaster. The inside walls of the opened drum containing saw fines in water showed extensive corrosion; none of the original surface was visible. Penetration of a drum as a result of corrosion could allow the water to drain. This in turn could allow the saw fines to dry out and ignite spontaneously. The insides of two other drums also showed extensive corrosion. Furthermore, the labeling of the drums is poor. For example, a drum labeled “fines” was empty, while a drum labeled “empty” contained chips.

The RFETS Health and Safety Manual procedure governing storage of chips states that they should be covered with water or coated with oil while in storage; chips stored longer than 7 days are required to have an oil coating [23]. This requirement was suitable when the chips were going to be stored for only a short time before being oxidized in the chip roaster, but is not appropriate now that the roaster has been shut down, and the chips are stored for longer periods of time. Moreover, even this requirement was not being observed. The chips in the drum were stored dry, and the saw fines were kept under water inside the inner drum. RFETS personnel stated that none of the uranium chips was coated with oil although all had been in storage for over a year.

Chips, turnings, and saw fines are not suitable forms for storage. Ideally, these forms would be oxidized in air under controlled conditions. At a minimum, they need to be stored in vented containers to prevent hydrogen gas buildup. By spring 1995, RFETS plans to either roast the chips or send them to NTS after immobilizing them in cement. The sludges are currently undergoing a safety review and are to be characterized. Sludges are not expected to contain any hazardous chemicals. Once any free liquids have been removed and the material certified, the sludges could be sent to NTS.

V. GENERAL STATUS OF ^{233}URANIUM STORAGE

Four sites in the DOE complex have over 1 kg of separated ^{233}U [24]:

- ORNL—Radiochemical Development Facility (RDF)
- LANL—Chemistry and Metallurgy Research (CMR) Building and the Plutonium Facility at TA-55
- Mound—T-Building
- LLNL—Buildings 251 and 332

A short discussion of the sources of ^{232}U and ^{233}U is provided in Appendix B.

A. Oak Ridge National Laboratory (Radiochemical Development Facility)

1. Inventory: The RDF currently stores 1,103 cans of ^{233}U, with 1,074 in steel- and lead-lined storage wells that are embedded in concrete. The remaining containers are currently stored in laboratory areas. Of the 1,103 cans, 1,054 contain oxides, 32 metal, and 17 salts (UF_4).

   There is a relatively small amount of ^{233}U stored as a nitrate solution in the P-24 tank, which contains a total of 16,000 liters of solution. No other ^{233}U residue or scrap is stored in the RDF.

2. Storage Conditions: The majority of the material is stored in four sets of top-loaded storage wells. One of the sets contains 68 wells, each consisting of a carbon steel pipe 30 ft in length, embedded in concrete. The other three sets of storage wells (consisting of a total of 26 wells) are located in the spaces separating the hot cells. These heavily shielded hot cells are no longer used, but contain contaminated processing equipment. Each of the storage wells 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 [25].

   The last time a shipment of material was received for storage at the RDF was in 1986. Cans have not been removed from storage since 1991. At that time, the six cans that were removed, which had been in storage for 8 years, showed no signs of deterioration. No containers have been retrieved from storage, repackaged, and returned to storage. A shipment of ^{233}U oxide is expected from the Mound Plant in late 1995.

   In general, when received for storage at the RDF, the material in the storage wells was packaged in screw-lid or welded-lid primary containers. These containers were removed from glove boxes, which were sometimes in plastic bags, and placed in food-pack cans (i.e., 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. Outer containers for the salt material were contaminated and bagged out of a glove box. These were not placed into food-pack cans, but inserted directly into the storage wells.

Some of the ^{233}U containers have been in storage for as long as 31 years (see Table 3).

Table 3. 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	3

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 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 inches 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.

There were 17 containers of UF_4 received from SRS and placed into storage in 1968. The material was separated and packaged from 1964 to 1965 and is about 60 weight percent uranium. RDF personnel stated that only these 17 containers will potentially need material stabilization. The need for stabilization will be determined based on the results of the planned container inspection in FY1998. Treatment processes for this potential stabilization have yet to be identified. However, as discussed in Chapter III, only bulk metal and uranium oxides (preferably U_3O_8) are suitable forms for long-term storage. If this material is to be placed into long-term storage, Board staff believe it would be advisable to consider conversion to oxide or metal.

RDF personnel have written a procedure for handling and storing ^{233}U [26]. This procedure provides requirements for receipt, handling, and nuclear criticality safety, but does not specify allowable forms, packaging requirements, or surveillance requirements. RDF personnel have developed draft criteria for acceptance of ^{233}U from Mound for storage at the RDF. These draft criteria include requirements for the inner and outer cans, as well as for material characteristics and container loading. However, the use of organic materials in the containers is permitted. By analogy with the standard for storage of plutonium, this practice appears inappropriate since the specific alpha activity for ^{233}U with hundreds of ppm of ^{232}U approaches that of weapons-grade plutonium. The maximum allowable loadings appear to have been derived from nuclear criticality safety concerns and not from concerns about possible pressurization of the container.

3. Storage Well Ventilation: Each of the storage wells has an exhaust header attached to the VOG system. This is a high-vacuum, low-flow system that also vents some Building 3019 process vessels. The primary flow path is out the east

side of Building 3019 via several ventilation lines, followed by a "Christmas tree" tie into the main header that goes to ground level. This main header bypasses the 3121 Filter Building before going underground to the Building 3039 stack, where scrubbers are located prior to the roughing and HEPA filters. A survey of the Building 3039 stack filter that was performed years ago, but not documented, disclosed nanocurie quantities of ^{137}Cs and ^{90}Sr 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 CEUSP campaign, not from the storage wells.

A branch of the VOG system ties into the Cell Off-Gas (COG) system prior to the "Christmas tree." The COG system is a low-vacuum, high-flow system for exhausting air from the VOG system upon a loss of the Building 3039 stack exhaust fans. The COG system air flows through roughing and HEPA filters before being released 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 in the COG ductwork had been fairly common.

In 1983, contamination was detected in two storage wells during a radiation survey of open storage wells. RDF personnel believe this contamination was the result of a breach of the outer plastic bag-out bag containing ^{233}U salt in a sealed container, not a leak of the sealed container. They conjecture that if a container had been leaking, the radiation levels would have been much higher. The packages in the contaminated well have been in storage for over 25 years. 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 could have occurred as a result of insufficient airflow. The VOG system exhaust piping 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 VOG system exhaust piping as a result of this occurrence. When the wells are opened, radiation surveys are not routinely performed.

B. Other Sites with Separated ^{233}Uranium

1. Los Alamos National Laboratory: Separated ^{233}U is currently stored in the CMR Building, Technical Area 18 (TA-18), and the Plutonium Facility at TA-55. In general, ^{233}U processing and handling have not occurred for several years because of the suspension of nuclear weapons testing.

   a. CMR Building: LANL personnel stated that there are 46 ^{233}U items currently in storage in the CMR Building, 31 of which are 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 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 is impossible to separate 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 slip-lid can/bag-out bag/slip-lid can combination.

LANL personnel have inspected all 31 items in anticipation of off-site shipment. However, the 2 metal items that interacted with the surrounding plastic may require processing prior to shipment or interim storage. Since the inspection of these 2 items resulted in the contamination of one hot cell, processing has been delayed. LANL personnel do not want to risk further contamination.

Of the remaining 15 items, 3 are metal, 5 are oxide, 5 are process residues, and 2 are solution. Except for the 2 solution items, these materials are packaged in the slip-lid can/bag-out bag/slip-lid can configuration.

b. 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 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.

c. Plutonium Facility: 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). There are several items that may contain machining turnings. Also in storage are 2 items containing ^{233}U-contaminated combustible cellulose rags. LANL personnel stated they do not believe these rags are nitrated. There are also about 10 items that contain process residues such as carbide, nitrate, and fluoride compounds and sulfate solutions [27].

LANL personnel stated that much of the ^{233}U oxide is contained in small welded stainless steel pipes placed in lead containers to attenuate the gamma radiation. Some of the residue items are in the common slip-lid can/bag-out bag/slip-lid can packaging configuration.

2. Lawrence Livermore National Laboratory: The inventory of ^{233}U at LLNL includes 50 items. Of these, 45 are stored in Building 332 and 5 in Building 251. The 50 items include metal, alloy, compounds such as oxides, and process residues. LLNL has not processed ^{233}U for over 6 years.

   LLNL personnel were unable to provide a more detailed breakdown for each of the four broad categories of items discussed above. They did state that a characterization program for the ^{233}U items (which would include records research and examination of items as necessary) is planned to begin in 1995.

   At LLNL, the packaging configuration generally used for all forms of ^{233}U is a crimp-sealed can/bag-out bag/crimp-sealed can configuration. In some cases, three crimp-sealed cans are used. These containers are then placed in lead containers to attenuate the gamma flux.

3. Mound Site: The Mound Site obtained ^{233}U oxide during the 1970s to provide a source of ^{229}Th, the first daughter from alpha decay of ^{223}U. Mound personnel separated the ^{229}Th from the ^{233}U and then stored the ^{233}U until sufficient ^{229}Th had grown into the material. It has been almost 15 years since the last separation process was run. The site currently has 28 items of separated ^{233}U. All of the material is an oxide with ^{232}U concentrations ranging from 2 to 16 ppm. The material is currently contained in glass jars stored inside lead-lined shipping-type containers that are no longer certified for shipping. Mound personnel are planning to repackage all of the material and ship it to the RDF at ORNL in late 1995.

C. ^{233}Uranium in Irradiated Fuel

The following is a brief discussion of significant quantities of ^{233}U contained in spent nuclear fuel. The fuels addressed in this section include those which contain ^{232}Th that has been irradiated and those in which ^{233}U is used as the fissile isotope and may or may not have been irradiated.

1. Idaho Chemical Processing Plant: The ^{233}U at ICPP is entirely in the form of irradiated and unirradiated reactor fuel and target material. It includes about 90 kg of ^{233}U contained in 744 irradiated Fort Saint Vrain reactor fuel assemblies that were received between 1980 and 1991 and currently are stored in CPP-603. In addition, about 46 kg of ^{233}U in 1,603 irradiated Peach Bottom fuel elements, received from 1968 to 1977, is stored in CPP-603 and CPP-749. About 524 kg of ^{233}U is contained in 48 elements stored in the CPP-749 dry wells. This irradiated fuel is from the Shippingport Light Water Breeder Reactor (LWBR) Program and was received from 1985 to 1987. In addition, 40 unirradiated LWBR elements that were received from 1984 to 1987 are also stored in CPP-749.

2. Oak Ridge National Laboratory (Molten Salt Reactor Experiment): The Molten Salt Reactor Experiment 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), lithium, zirconium, and beryllium fluoride salts. Approximately 4,650 kg of these salts is stored in two storage tanks, with about 31 kg being ^{233}U.

   Recent radiation surveys indicate that several kilograms of the uranium may have been converted over the years from a tetrafluoride compound to a hexafluoride that migrated to a charcoal filter pipe, where it cooled, recrystallized, and formed uranium tetrafluoride. This situation has raised nuclear criticality safety concerns since the pipe was immersed in water for some time. Recently, the water was removed from this area.

3. Savannah River Site: SRS has ^{233}U contained in irradiated material. This material is contained primarily in five ^{233}U fuel bundles that were irradiated in the Dresden reactor about 25 years ago. This fuel is stored in the Receiving Basin for Offsite Fuel (RBOF). Also stored in the reactor basins are 17 Mark 50 ^{232}Th target slugs that contain ^{233}U. In addition, RBOF has two other fuel bundles that contain ^{233}U.

VI. CONCLUSIONS

The general conclusions of this report are as follows:

- There are no pressing, widespread safety issues with uranium and thorium in storage in the DOE complex, although there are safety issues with a few specific materials at specific sites.

- FEMP and RFETS have some uranium metal chips, turnings, and saw fines in storage. These may be pyrophoric, and processing them into more stable forms as soon as possible is a priority.

- FEMP, RFETS, and the Y-12 Plant have uranium and reactive metal stored in unvented drums. Hydrogen gas generated in these drums may be accumulating and poses a serious fire hazard. Venting the drums or removing the metal from them would solve this problem.

- The condition of many ^{233}U containers stored at ORNL is uncertain. Examining a representative number of containers to verify that this hazardous material is properly contained would be advisable.

- ^{233}U metal foils and salts at ORNL and process residues and improperly packaged materials at LANL and LLNL are not suitable for long-term storage and may need to be converted to stable forms, such as oxide or bulk metal.

APPENDIX A: URANIUM AND THORIUM HAZARDS

I. Uranium: General

Principal uranium hazards of concern include accidental nuclear criticality, inhalation of particulate materials, fire and explosion, and container pressurization [5, 28]. Nuclear criticality safety was beyond the scope of this review. Airborne releases of finely divided uranium-containing materials could occur from fire, criticality excursion, or violent destruction of a containment vessel.

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.

If unsintered uranium dioxide is finely divided, it can be pyrophoric. This finely divided dioxide can form pyrophoric uranium hydride during anaerobic corrosion of uranium metal by water:

$$2\ H_2O + U\ \mathrm{Y}\ UO_2 + 2\ H_2$$

Some of this hydrogen then reacts to form uranium hydride:

$$3\ H_2 + 2\ U\ \mathrm{Y}\ 2\ UH_3$$

Large pieces of uranium metal react with moisture in air until an oxide layer forms on the surface and prevents 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. Uranium metal contacting the drum wall and the spontaneous ignition of pyrophoric materials can provide such a spark ignition source [18].

Besides hydrogen ignition, 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 x 10^8 and 4 x 10^9 years, respectively) that most of the activity in HEU comes from ^{234}U, which has a half-life of 2 x 10^5 years, although it makes up only 1 percent of the uranium. In addition, ^{235}U and ^{238}U emit few gamma rays and have low spontaneous fission rates [29].

II. ^{233}Uranium and ^{232}Uranium

^{233}U poses some unique hazards as compared with HEU. ^{232}U and ^{233}U have specific alpha activities 10^7 times higher and 4.4 x 10^3 times higher than ^{235}U, respectively. These isotopes must be handled in glove boxes 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 ^{232}U, ^{233}U, and their decay products cause high neutron production through (α,n) reactions with elements, such as fluorine and aluminum, that have high probabilities for such reactions. As the concentration of ^{232}U in the ^{233}U increases to over 100 ppm, the specific alpha activity approaches that of weapons-grade plutonium, especially as the uranium radioactive decay products approach equilibrium with the uranium. Thus, concerns similar to those associated with the packaging of plutonium in contact with plastic are applicable [30].

^{232}U also poses a unique hazard because of the 2.6 MeV gamma that is emitted by the radioactive decay product ^{208}Thallium (^{208}Tl). To gain a perspective of the significance of ^{232}U, a typical package containing 3 kg of uranium with 100 ppm ^{232}U would result in a radiation field of about 25 rem/h of gamma radiation 1 ft from the package. Thus, the storage and handling requirements for ^{233}U include substantial shielding to protect workers and the public.

III. Thorium

Thorium metal tarnishes slowly in air at room temperature and corrodes slowly in water below 100°C. The formation of a protective oxide film slows further attack. Finely divided thorium metal is pyrophoric. Thorium poses airborne release, container pressurization, and fire and explosion hazards similar to those previously discussed for uranium.

Natural thorium is found as ^{232}Th and its daughter products. The daughters multiply the total alpha activity of a given mass of thorium by a factor of more than 6. Because of their short half-lives, the daughters reach secular equilibrium fairly quickly. Two of the daughters emit hard gammas: ^{228}Ac's 915 keV and ^{208}Tl's 2.6 MeV. In addition, one of the daughters, ^{220}Rn, is a gas, although its short half-life of 55 seconds reduces the distance it is likely to migrate. Irradiated thorium is much more hazardous because of the formation of ^{232}U, ^{233}U, ^{228}Th, and their daughter products [28].

APPENDIX B: FORMATION OF ^{232}URANIUM AND ^{233}URANIUM

I. ^{232}Uranium

^{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 over 100 ppm. ^{232}U is formed primarily via four sets of nuclear reactions.

The first and predominant path includes a (n,2n) reaction with ^{232}Th (natural thorium) to produce ^{231}Th. ^{231}Th subsequently decays (half-life of 25 hours) by beta emission to ^{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 a (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. The ^{237}U subsequently decays (half-life of 6.7 days) by beta emission to ^{237}Np. ^{237}Np then undergoes a (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.

II. ^{233}Uranium

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

ACRONYMS

ANL-W	Argonne National Laboratory-West
B&W	Babcock and Wilcox
Board	Defense Nuclear Facilities Safety Board
CEUSP	Consolidated Edison Uranium Solidification Project
CMR	Chemistry and Metallurgy Research
COG	Cell Off-Gas
DOE	Department of Energy
DOT	Department of Transportation
DU	Depleted Uranium
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
HEPA	High-Efficiency Particulate Air
HEU	Highly Enriched Uranium
ICPP	Idaho Chemical Processing Plant
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National Laboratory
LEU	Low-Enriched Uranium
LOI	Loss on Ignition
LLNL	Lawrence Livermore National Laboratory
LLRW	Low-Level Radioactive Waste
LWBR	Light Water Breeder Reactor
MT	Metric Ton
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
RBOF	Receiving Basin for Off-site Fuel
RCRA	Resource Conservation and Recovery Act
RDF	Radiochemical Development Facility
RFETS	Rocky Flats Environmental Technology Site
SRS	Savannah River Site
TSCA	Toxic Substances Control Act
UFSF	Unirradiated Fuel Storage Facility
UNH	Uranyl Nitrate Hexahydrate
VOG	Vessel Off-Gas

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Review of the Safety of Storing Plutonium Pits at the Pantex Plant

Defense Nuclear Facilities Safety Board

Technical Report

November 25, 1997

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Review of the Safety of Storing Plutonium Pits at the Pantex Plant

This report was prepared for the Defense Nuclear Facilities Safety Board by the following staff members:

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November 25, 1997

Preface

In accordance with its enabling statute, the Defense Nuclear Facilities Safety Board (Board) continues to review the design and construction of new Department of Energy (DOE) defense nuclear facilities. This report is part of a continuing, long-term effort by the Board's staff to review plutonium pit storage facilities and related activities at the DOE Pantex Plant. This report reflects key events during the last 5 years, through November 1997.

In December 1997, the Board conducted an on-site review at Pantex and discussed issues related to safe pit storage with DOE and its weapon design agencies. During these discussions, DOE identified several new initiatives that are not covered in this report but could affect safe pit storage. The main body of this report was written before the December 1997 review, and so it does not reflect the changes in plans that were revealed during that review. The changes include the following:

- On November 4, 1997, the design agencies issued a draft pit storage specification with moisture controls. These controls, coupled with active cooling in facilities, will minimize pit corrosion and will likely require the pits to be stored in sealed containers. The latter would provide a second barrier against release of plutonium during postulated accidents.

- On December 3, 1997, and again on December 10, 1997, DOE informed the Board of DOE's goal to have all the pits in a dry environment within 3 to 4 years.

- On December 3, 1997, DOE also informed the Board that decisions regarding design modifications to the current pit containers (AL-R8) had been delayed by 2 months. Although this means that pits received from Rocky Flats will need to be repackaged, the delay provides DOE an opportunity to develop a consistent set of requirements.

- On December 5, 1997, DOE decided to increase the number of Zone 4 magazines with active cooling and to discontinue efforts to consolidate surplus pit storage in a single building in Zone 12 (Building 12-66). Despite intensive study since the January 1997 record of decision on fissile material storage and disposition, DOE has not shown that this consolidation would have provided a net safety improvement. Providing additional actively-cooled magazines will slow pit corrosion and protect temperature-sensitive pits.

- On December 10, 1997, DOE provided the Board an outline for an integrated pit storage program plan. Key elements of the plan are (1) assumptions and constraints, (2) requirements and success criteria, (3) program elements needed to meet those requirements, (4) organizational interfaces, and (5) deliverables, schedule, and cost. DOE expects to have a draft plan by the end of January 1998.

These initiatives will address some of the issues raised in this report, if they are implemented in a timely manner. The process of developing an integrated program plan also provides DOE an opportunity to systematically consider the remaining issues, which may ultimately improve the safe storage of pits.

EXECUTIVE SUMMARY

A pit is the central core of a nuclear weapon, and typically contains an inner shell of plutonium and an outer shell of stainless steel or beryllium. This report examines the safety of the storage of plutonium pits at the Department of Energy (DOE) Pantex Plant by systematically considering pit containers, environmental controls, storage facilities, and surveillance programs. Taken together, these components, systems, facilities, and programs serve to protect the pits from damage and to contain any special nuclear materials that may be released from a breached pit. Failure of the pit outer shell, or clad, would allow corrosion of plutonium metal and formation of powdery oxides that could then contaminate the workers, the facilities, and the environment, if not contained.

DOE is currently using a new container design for some pits, developing another, less expensive container for the remaining pits, and making preparations to move thousands of pits to different storage facilities at Pantex. These efforts are not well integrated. For example, it appears that DOE has not evaluated completely how changes in container design affect storage facility requirements. Likewise, DOE has not assessed whether the near-term cost savings that result from implementing the less expensive containers, which are not certified for off-site shipment, will be outweighed by the costs and risks of possible repackaging later if off-site shipments are ultimately required.

In addition, DOE has not thoroughly evaluated the overall change in safety posture at Pantex that will result if, as planned, thousands of pits are moved from their current storage locations to different Pantex facilities. The current course of action being pursued by DOE could result in a Pantex facility being used to store the largest plutonium inventory in the DOE complex, but the chosen facility is not clearly adequate. A systematic review of the requirements for this storage facility needs to be performed.

Environmental controls are essential to preserve the integrity of several temperature-sensitive pit types. The lack of authorization basis controls for the storage of these pits renders at least three temperature-sensitive designs vulnerable to cladding failure. Pantex has implemented in procedures the safety-related temperature limits identified by the design agencies, but formal authorization basis controls would better ensure that the temperature control systems and practices are effective and reliable.

The relatively new surveillance program for pits stored at Pantex does not appear to be sampling the pits at a rapid enough rate to characterize in a timely manner the real potential for corrosion of the stored pits. Only about 30 pits per year are inspected, even though more than 10,000 pits of various designs are stored at Pantex. The resolution of corrosion and packaging issues is hindered further by the lack of a formal project to improve understanding of pit cladding corrosion and identify corrective actions that may be required.

TABLE OF CONTENTS

1. INTRODUCTION

A pit is a major nuclear weapon component and typically contains plutonium within an outer metal shell or clad. The Department of Energy (DOE) currently stores in excess of 10,000 pits at the Pantex Plant near Amarillo, Texas.

Since 1989, the pits stored at Pantex have been not only growing in number but also aging. Nearly all the pits are in containers that are not hermetically sealed, and most of these containers are stored in passively cooled magazines with essentially no confinement features. Therefore, the outer metal shell, or clad, of the pit functions as the primary confinement for plutonium, and for pits in magazines, the only reliable confinement.

Cladding failure would allow air to enter the pit, resulting in corrosion of the plutonium within. Normal Pantex operations do not involve unencapsulated plutonium, so a cladding failure would present several potential new hazards: (1) internal and external contamination of facility workers who might unknowingly open a package containing a failed pit; (2) potential facility contamination outside of an unopened pit storage container, since most containers are not hermetically sealed; and (3) an increase in the releasable quantity of plutonium if a major facility accident breached the clad. It is important that pits with breached clad be promptly recognized and mitigated, since plutonium oxides are much more dispersible than plutonium metal.

This report examines the safety issues associated with storing plutonium pits at Pantex by systematically considering pit containers, environmental controls, facilities, and surveillance programs. Section 2 provides background information and describes recent DOE activities related to pit storage and integrity. Design features and systems that prevent release of the plutonium from the stored pits are discussed in Section 3. Section 4 describes the surveillance programs intended to ensure the adequacy of pit storage conditions. Issues related to pit storage are discussed in Section 5. Conclusions are presented in Section 6.

2. BACKGROUND

This section provides an overview of pit storage programs and relevant correspondence between DOE and the Defense Nuclear Facilities Safety Board (Board).

2.1 OVERVIEW OF PIT STORAGE PROGRAMS

Nuclear weapons returned from the stockpile for inspection or dismantlement are shipped to the Pantex Plant, where the pits are removed. Until 1989, most pits removed from weapons at Pantex were eventually shipped to the Rocky Flats Plant (since renamed the Rocky Flats Environmental Technology Site) to be recycled into new weapon components. Plutonium operations at Rocky Flats were curtailed in 1989, and pits from dismantled weapons have been accumulating at Pantex since then. The increasing number of older pits has raised questions involving their safe storage at Pantex, particularly with regard to temperature-related failure modes for the pit clad, the lack of confinement for containers and facilities, and the capability of facilities to withstand externally driven accidents.

In 1992, DOE initiated several activities to ensure continued safe pit storage. These activities included (1) relocating most of the pits with identified safety-related temperature limits to two magazines with active cooling, (2) planning a surveillance program focused on pits removed from the stockpile and placed in storage, and (3) planning a repackaging program to place pits in a new type of container (AT-400A) that features a welded inner containment vessel filled with an inert gas. The AT-400A containers would protect the pits from corrosion and provide containment if the pit clad should fail. DOE also planned to certify these containers for off-site shipment. Eventually, DOE intended to repackage all pits into these containers for an interim period of approximately 20 to 40 years until a final disposition option is chosen and implemented. As discussed later, these initiatives have generated mixed results.

In 1994, DOE completed a plutonium vulnerability assessment that included pits at Pantex.[1] The final report states that the most significant plutonium vulnerability at Pantex is total reliance on the outer metal shell of a pit as the only barrier to prevent plutonium oxidation and release (Summary, p. 52). Furthermore, the report states that pits have not been tested or qualified for extended storage, and that detailed surveillance data are needed to understand potential failures involving joint designs, fabrication variations, and characteristics of aged material. At the time the DOE report was prepared, repackaging of pits into the sealed AT-400A containers was expected to mitigate many of these concerns. The Pantex-specific assessment indicated that repackaging was expected to start in 1995 and to be completed within 5 years (Volume II, Part 12, p. 9).

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[1] DOE/EH-0415, "Plutonium Working Group Report on Environmental, Safety and Health Vulnerabilities Associated with the Department's Plutonium Storage," November 1994.

In parallel with pit surveillance and repackaging activities, DOE has been developing plans to remove pits from Zone 4 and consolidate pit storage at Pantex in upgraded facilities in Zone 12. DOE described these plans in December 1996 in a programmatic environmental impact statement for fissile material storage and disposition (the storage and disposition PEIS), which was followed by a record of decision in January 1997.

The storage and disposition PEIS, the record of decision, and other program documents state that strategic reserve pits will be consolidated into the Special Nuclear Material Component Staging Facility (12-116) starting in May 1998, and that non-strategic-reserve pits (i.e., surplus pits waiting to be dispositioned) will be moved into an upgraded facility (12-66) by 2004, and possibly as early as 2001. Within about two decades, the surplus pits would be permanently dispositioned using facilities that could be built either at Pantex or at another site. The DOE storage and disposition strategy is, however, subject to a number of uncertainties.[2]

The upgraded Zone 12 pit storage facilities are required to protect the pits from postulated external threats ranging from earthquakes to tornadic missiles and airplane crashes. The planning documents cited above indicate that AT-400A containers will be relied upon to provide part of this protection. For example, the storage and disposition PEIS, under preferred alternative (p. 2-53), states that "...pits would be placed in storage in Zone 4 West pending availability of AT-400A containers and relocation to upgraded facilities in Zone 12 South." Another example is the discussion related to aircraft crash accidents in the 1996 Pantex Plant Final Environment Impact Statement (p. 4-309), which states "In the future, pits will be stored in a new container, the AT-400A, that will provide additional thermal and impact protection."

2.2 PREVIOUS DOE/BOARD CORRESPONDENCE ON PITS

In 1995, DOE established the position that authorization basis controls on the pit clad, including temperature limits, are not required. The authorization basis is defined as those aspects of the facility design basis and operational requirements that are important to safety and relied upon by DOE to authorize operation. DOE based this position on the fact that analyses of accidents involving combined plutonium and high explosive assume no clad is present. DOE acknowledged, however, that the clad acts as a defense-in-depth barrier to release during long-term storage.

Beyond the clad, the next possible barrier to release is the container. In the same correspondence, DOE stated that safety classification for containers should be based on the results of contractor-supplied safety analyses.[3] Specifically, classification would depend on whether the containers fulfill a preventive or mitigative function that limits public exposure below

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[2] GAO/RCED-97-98, "Department of Energy Plutonium Needs, Costs, and Management Programs," April 1997.

[3] L. D. Rigdon (DOE-AL) memo to G. W. Johnson (DOE-AAO), dated October 26, 1995.

evaluation guidelines for postulated accidents. At Pantex, the evaluation guideline is interpreted to require that the maximally exposed off-site individual receive less than 25 rem committed effective dose equivalent because of an accident.

In a letter dated May 10, 1996, the Board commented to DOE that the pit clad is an important safety barrier, particularly for the protection of workers and the environment, and that implementing appropriate technical safety requirements (TSRs) would be consistent with the previous DOE plutonium vulnerability assessment. This assessment reflected the fact that Pantex safety analyses for operations involving pits but no high explosive routinely assume that the clad prevents plutonium oxidation before an accident occurs.

On July 15, 1996, DOE responded to the Board's May 1996 letter. The response stated that the pit clad is a design feature of the nuclear weapon and provides defense-in-depth, that clad breaches have been rare and resulted in insignificant consequences, that pits from sealed weapons examined as part of the Stockpile Evaluation Program have shown no corrosion, and that a surveillance program has been developed for pits in interim storage at Pantex.

In the same letter, DOE also stated that the Pantex contractor, Mason and Hanger Corporation (MHC), is monitoring and, in some cases, controlling pit storage temperatures as a prudent measure. Furthermore, there are air conditioners installed in two Zone 4 magazines to control temperatures in W48 pits—the only pit type considered at that time to require special environmental controls (as discussed later, two other pit types with safety-related temperature limits have subsequently been identified). DOE stated that controlling pit temperatures will provide the necessary assurance against clad failure during staging until the pits are repackaged in AT-400A containers or otherwise dispositioned.

3. THE PIT STORAGE SYSTEM

The pit storage system at Pantex can be considered as a series of barriers to release (e.g., the clad, container, vault, and building) and the programs and controls associated with maintaining those barriers. In the past, DOE has required that at least one barrier be a confinement barrier for material that is not readily dispersible, such as monolithic plutonium metal (DOE Order 6430.1A). The degree of confinement is required to suit the most restrictive hazard anticipated. Typically, the clad or container is considered the primary confinement and is required to withstand normal operations, anticipated operational occurrences, and design basis accidents.

Pantex currently stores in excess of 10,000 pits. Most pits are stored in non-hermetically sealed AL-R8 containers in Zone 4 magazines that also provide little confinement. Several hundred pits in AL-R8 containers are staged in Zone 12 facilities (e.g., 12-44 Cell 8).

Although some pits reportedly have been at Pantex for decades, in the past most pits were returned to Rocky Flats to be recycled into new weapon components. Since 1989, when Rocky Flats discontinued receiving and remanufacturing pits, the Pantex pit population has been growing and aging. As a result, new questions involving long-term pit integrity have been raised, particularly for conditions beyond previous experience, such as long-term exposure to the environment outside of a sealed weapon.

3.1 PIT INTEGRITY

A pit contains an inner metal shell, typically plutonium, and an outer metal shell or clad, typically stainless steel or beryllium. The clad provides a hermetic seal, protects the plutonium metal from oxidizing, and prevents plutonium from migrating beyond the clad. In addition to confinement requirements, the pit clad designs are controlled by weapon design requirements that result in robust shells protecting the plutonium.

After a pit has been removed from a weapon, the pit clad is the only remaining confinement for the plutonium inside the pit. If the clad is intact, the predominant hazards involve external radiation exposure during normal handling or during an unlikely event, such as an inadvertent criticality. Pantex addresses these hazards by using shielding and administrative controls.

The pit clad has several potential failure modes. Corrosion by pitting can occur in the presence of moisture and chlorides, even though the pit clad is made of corrosion-resistant materials. Galvanic corrosion is also possible at joints involving dissimilar metals if the pits are not kept in a dry environment. Differential thermal expansion can induce stresses that could cause the clad for some pit designs to fail. Lastly, mechanical damage can occur during operations involving pit handling or during postulated transportation and facility accidents. The design agencies have reported that most observed instances of pit damage have been due to mishandling.

If the pit clad were to fail, the plutonium inside would oxidize, become dispersible, and represent an inhalation hazard. These oxides could also swell and strain the clad since the oxides are less dense than plutonium metal. This process could lead to continued cracking of the clad and further oxidation of the plutonium. Atmospheric humidity would accelerate this degradation. This type of hazard has rarely been encountered at Pantex.

3.2 PIT CONTAINERS

This section describes the containers commonly used to store or ship pits: the AL-R8, the AT-400A, and the FL containers.

3.2.1 AL-R8 Containers

The current pit storage container used throughout Pantex, Rocky Flats, and elsewhere in the weapons complex is the AL-R8. The AL-R8 is an unsealed drum containing fiberboard packing material (Celotex) and a metal support fixture for the pit. The drum is made of carbon steel that is coated to minimize corrosion. The AL-R8s offer little confinement since they are unsealed and prone to corrode if the coatings are missing or become degraded.

AL-R8s are still used for on-site movement of pits, but are no longer certified for off-site transportation. For certification, the Nuclear Regulatory Commission now requires sequential application of a series of tests of hypothetical accidents, including (1) a 30 ft drop of the container, (2) a dynamic crush caused by dropping a 1100 lb load 30 ft onto the container, (3) a 40 inch drop of the container onto a 6 inch diameter steel bar, (4) a half-hour fuel fire, and (5) immersion under 3 ft of water (10 CFR 71.73). Pantex facility design documentation indicates that the AL-R8 does not meet the dynamic crush test.

3.2.2 AT-400A Containers

In recognition of the fact that the AL-R8 is neither a reliable confinement nor a certified shipping container, DOE has developed an improved container, the AT-400A. The AT-400A is a stainless steel drum with a welded stainless steel inner containment vessel filled with an inert gas. The containment vessel would protect the pit from corrosion and prevent plutonium from migrating outside the container if the pit clad were to fail. DOE has intended but has not yet obtained certification of the AT-400A containers for off-site shipment.

DOE originally planned to repackage most pits into AT-400A containers. During 1997, DOE and MHC continued preparations for this effort. Major obstacles encountered late in the project included the need to design and install engineered safety features to prevent burn-through of the inner containment vessel during automatic welding, which would potentially damage the pit. These obstacles have been overcome, and the first pits were repackaged in August 1997.

Over time, the scope of the AT-400A project has narrowed. At various times, the project's scope included manual, mechanical, and robotic packaging lines at Pantex, with a total capacity of about 2000 pits per year. At present, the maximum estimated throughput is about one-tenth of that. The project now consists of one manual line, rated at 20 pits per month, which may be replaced in the future by a mechanical line, rated at 40 pits per month. Current DOE program plans include repackaging only one pit type, the W48, into the AT-400A containers and only completing certification of the W48 configuration for off-site shipment. At current repackaging rates, it could take more than 2 years to repackage just the W48 pits.

The shift in scope of the AT-400A program from all pits to only the W48s was apparently driven by the high container costs, the recent decision to dispose of surplus pits within roughly two decades, and the uncertainty regarding whether future facilities for the final disposition of pits will be located at Pantex or elsewhere. To compensate, DOE has started to design a sealed inner container for the existing AL-R8s. Since neither the original nor the modified AL-R8 design is being certified for off-site shipment, this alternative is likely to require either overpacking current containers or repackaging pits (again) if facilities required for pit disposition are not located at Pantex.

3.2.3 FL-Type Containers

Since 1991, the FL-type container has been the only design certified for off-site pit shipments. FL containers have stainless steel inner and outer vessels, separated by Celotex. The inner vessel has a bolted closure and a dual concentric elastomer seal. Because of the small number of FL containers (less than 300) and concerns about long-term degradation of the elastomer seal, these containers have not been considered for use for long-term storage.

3.3 PIT STORAGE FACILITIES

This section describes pit storage facilities at Pantex. Currently, most pits are stored in the Zone 4 magazines. In 1996, a concept was proposed that would involve closing Zone 4 after 2002 and consolidating all the pits in Zone 12 facilities, thereby reducing Pantex security costs. As recently as August 1997, the driving motivation for this concept was a perceived need for only a few magazines past 2002. More recently, Pantex personnel have stated that Zone 4 closure in the near future may not be possible. Specifically, because of treaties now under consideration, magazines may still be needed to store weapons that are to be dismantled after 2002. Under this scenario, Pantex personnel consider that there may not be enough magazines to hold all the returned weapons and the surplus pits.

Regardless of the precise reason, DOE is now planning to consolidate all the pits in Zone 12 facilities, as identified in the storage and disposition PEIS and the corresponding record of decision. Strategic reserve pits, numbering up to 4000, would be stored in the Special Nuclear Material Component Staging Facility (12-116). The remaining pits, possibly as many as 12,000, would be moved to a hardened warehouse, the 12-66 facility.

3.3.1 Zone 4 Magazines

Zone 4 has 60 magazines used to store pits, nuclear weapons, and other major components. The magazines are of two designs: 18 are modified Richmond (MR), and 42 are steel arch construction (SAC). Approximately half the magazines are now used for pit storage.

An MR magazine is essentially a concrete box, with a center dividing wall and a 3 ft earth overburden. These magazines were built in 1944 and upgraded in 1961. The roofs are prestressed concrete. The internal dividing walls and the exposed front wall are reinforced, while the back and side walls are unreinforced. Both the MR and SAC magazines have doors made of steel plate that are blocked by massive reinforced concrete barriers. Each of the two sections of an MR magazine can hold 212 pits.

The SAC magazines were constructed in 1965 to U. S. Air Force specifications in adjacent groups of three or five. Each magazine consists of reinforced concrete end walls and a corrugated steel arch that is covered by a 3 ft earth overburden. The steel arch rests on reinforced concrete stem walls. Each SAC magazine can hold 252 pits.

Capacity to mitigate an aircraft crash remains an open question for many Pantex facilities, including the magazines. MHC has been evaluating this hazard at the site level using the approach from a DOE standard on aircraft crash accident analysis (DOE-STD-3014-96). MHC has already completed evaluations indicating that the magazines can withstand other design basis and beyond design basis events (e.g., 220 mph tornadic winds, a 0.33 g earthquake, and an accidental external blast).

Decay heat from pits results in magazine heat loads in the low kilowatt range. The magazines rely on passive cooling, except for two air-conditioned MR magazines that contain most of the W48 pits. In 1993, the design laboratories began defining maximum allowable storage temperatures above which the laboratories could not guarantee pit integrity or quality. In a parallel and coordinated effort, MHC initiated a temperature monitoring program for the pit magazines. This program has been one of the better managed and coordinated activities involving pits at Pantex. However, there are no authorization basis controls on pit or magazine temperatures or on maintaining active cooling for the two magazines containing W48 pits.

3.3.2 Special Nuclear Material Component Staging Facility (12-116)

The 12-116 facility was designed in 1988, and initial construction was completed in 1993. The hazards associated with this facility will be attached to staging and inspection of pits, secondaries, and tritium reservoirs. The facility has never operated. A backfit design has been initiated to add new capabilities and correct existing design and construction deficiencies.

Operations are planned to begin in May 1998, but the need to resolve open safety questions will limit the facility's pit inventory until post-startup modifications have been completed. These modifications would also add capabilities such as the use of automated guided vehicles in the vaults to minimize personnel radiation exposure.

During the last 2 years, there have been major perturbations in the 12-116 backfit process. The major change since initial design has been a roughly five-fold increase in the intended pit inventory. The facility's primary mission has shifted from staging pits for weapon assembly to providing longer-term interim storage for as many as 4000 strategic reserve pits. During this time, other major functions and capabilities, such as a robotic pit packaging system for AT-400A containers, have also been planned and then withdrawn.

In general, the 12-116 structural design criteria were equivalent to or more rigorous than recent DOE requirements (see the Appendix). When completed, the 12-116 building design was controlled more by enhanced security requirements than by design basis accidents. This resulted in robust features such as concrete walls that are 2 ft thick with four layers of rebar reinforcement. Analyses have shown that the building would remain elastic and intact during design basis accidents, such as tornadoes, earthquakes, or blasts from nearby explosive facilities.[4] Furthermore, a DOE-sponsored review indicated that the building structure could meet code requirements for safety-class structures with only minor deviations.[5] The margin of safety that resulted from the enhanced security requirements is sufficient to compensate for these deviations.

3.3.3 Prospective Surplus Pit Storage Facility (12-66)

The 12-66 facility was built in 1973 and is currently used to store weapon secondaries and other components. MHC is preparing a conceptual design for upgrading 12-66 to a surplus pit storage facility by 2002. Preliminary design (Title I) was expected to start in November 1997 but is now on hold. If 12-66 is upgraded as currently envisioned, it may potentially contain more plutonium than any other facility in the DOE complex.

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[4] Engineering Research and Applications Division, Brookhaven National Laboratory, "Structural Evaluation of Building 12-116 SNM Component Staging Facility at Pantex Plant, Amarillo, Texas," November 1995.

[5] Science Applications International Corporation, "Review of Pantex Building 12-116 Structure for Compliance with Current Codes for Safety Class Design and Construction," November 1995.

This facility is basically a hardened warehouse with outer walls made of 1 ft thick concrete with two layers of rebar reinforcement (i.e., half the wall thickness of 12-116). The roof is constructed of reinforced concrete and is supported by the outer walls and 21 internal columns. Other than the columns, the facility has no internal structure that could resist the lateral loads typical of accidents such as tornadoes and seismic events.

According to a 1996 MHC safety analysis report, the building was designed to meet 1970 Nuclear Regulatory Commission requirements for a tornado-resistant structure (i.e., 360 mph tornadic wind, 54 lb timber missile at 125 mph, and 3 psi differential pressure, dropping at 1 psi/sec). The safety analysis report indicates that the structure would not fail during a 0.1 g earthquake, but concrete cracking and spalling could occur. This loading corresponds to that of a Uniform Building Code essential facility, such as a fire station, with no confinement function. Some structural failure modes, such as column collapse, are not included in this evaluation.

4. PIT SURVEILLANCE ACTIVITIES

This section summarizes routine pit inspections and pit surveillance programs at Pantex. DOE conducts several surveillance programs to evaluate the condition of pits. The extent of surveillance for each pit type depends on whether that type represents an active or retired weapon, or is considered to be a strategic-reserve pit. Historically, the principal purpose of pit surveillance was to ensure that the stockpile environment and aging of materials did not adversely affect weapon safety and reliability. However, as the number of pits from retired weapons stored at Pantex has grown in recent years, there has been a new emphasis on ensuring safe pit storage. This concern is particularly important because the precise condition of each pit after weapon disassembly is not well documented, and the long-term behavior of pits stored outside of weapons is not well characterized or understood.

4.1 ROUTINE INSPECTIONS AT PANTEX

After each weapon is dismantled at Pantex, limited inspections are performed to assess the integrity of the pit before it is transferred to a storage facility. Each pit is inspected visually and checked for external contamination. Some specific pit types are routinely weighed. Some are leak checked, but only a fraction of the pits now in Zone 4 were leak checked before being moved to Zone 4.

Required periodic inspections of pit magazines at Pantex are unlikely to detect pits that have suffered cladding failures unless contamination migrates out of the pit container. Although the magazines are surveyed periodically for contamination, pit containers are not opened during these inspections.

4.2 PIT SURVEILLANCE PROGRAMS

The design agencies, Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL), manage several programs that assess the condition of pits both in weapons and in storage containers at Pantex. The three key programs are (1) the cycle testing of weapons; (2) the shelf-life program, involving pits representative of active weapons and strategic-reserve pits; and (3) the storage surveillance program, involving pits stored at Pantex. Additionally, under the Enhanced Surveillance Program, DOE has been developing a methodology for predicting pit lifetimes. This work centers on age-related changes in special nuclear materials, and how aging phenomena affect the performance of weapons.

4.2.1 Cycle Testing of Weapons

Weapons undergo surveillance on a 1-year cycle. Active weapons are sampled for surveillance at the rate needed to provide a 90 percent confidence level for detecting 10 percent defectiveness during a 2-year period. This equates to a sample size of approximately 11 units per year for each of the weapon types in the active stockpile. This sampling frequency has proven adequate to ensure that pits remain intact in the stockpile environment.

Weapons selected for cycle testing are disassembled and inspected at Pantex. The nature and extent of inspection applied to a particular weapon depend upon weapon design characteristics and information needs. When the pit is inspected, some combination of the following examinations may be performed: visual inspection, inspection for external contamination, radiography, leak testing, weighing, and vapor sampling. For each weapon type, one pit per year is destructively evaluated by the design agency.

For inactive weapons, the sampling protocol is different. For retired weapons awaiting dismantlement, surveillance is left to the discretion of the design laboratories. Every 5 years following retirement status, the DOE Albuquerque Operations Office (DOE-AL) formally requests the design agency to certify the safety of these systems. If dismantlement is scheduled within 2 years, surveillance inspections are not done unless the design agency considers them to be necessary. This means a disassembly campaign may begin following a multiple-year hiatus in pit surveillance. However, not all weapon systems have been subject to surveillance at even these frequencies. More frequent surveillance may be appropriate from the perspective of hazard identification and control implementation as the Pantex Plant prepares for a disassembly campaign that may involve hundreds of weapons.

4.2.2 Shelf-Life Testing

The shelf-life testing program is intended to evaluate the stability of properly sealed pits for as long as they are representative of weapon components in the active stockpile or the strategic reserve. About 80 pits are stored at LANL for this program. The pits are identical to actual weapon components, except for special tubing and valving added to facilitate routine gas sampling. As the name implies, this program allows these pits to age on the shelf, with periodic nondestructive testing to ensure that the gases inside the pit remain stable and that the interior of the pit is not degrading. The principal test is vapor sampling to check for changes in the gas composition inside the pit. The pits are also weighed and subjected to tests such as radiography and ultrasonic inspection.

4.2.3 Storage Surveillance Programs

Cycle testing provides excellent information about pits that have been maintained in a weapon environment. However, the environment in a non-hermetically sealed pit storage container at Pantex is considerably different from that inside an assembled nuclear weapon. The storage surveillance program is a relatively new effort intended to assess the condition of pits stored at Pantex. It addresses concerns such as the potential for breaches of the pit cladding due to corrosion, exposure to elevated temperatures, or damage incurred during weapon dismantlement. This is also the only program that addresses the thousands of non-strategic-reserve (surplus) pits stored at Pantex.

The design agencies have devised sampling strategies that group the surplus pits by their basic design features, such as materials of construction and gas fill. The number of pits inspected each year is based on design agency expectations that pits will degrade slowly and on the available resources at Pantex and the design agencies. It is not based on a statistical protocol. About 30 pits are removed from storage each year and nondestructively evaluated at Pantex. A smaller number of pits (one or two for each laboratory) are returned to the design agencies for more comprehensive nondestructive and destructive evaluation.

The exact inspections vary depending on the type of pit being tested. Nondestructive evaluation typically includes visual inspection, swiping for external contamination, leak testing, gas sampling, radiography, and weighing; however, some pit types are only inspected visually and checked for external contamination. Examinations of pits selected for destructive evaluation typically include visual inspection followed by metallography, chemistry, and tensile testing. When inspections reveal abnormal conditions, more pits of that type are sampled. For example, B54 pits have been visually inspected based on conditions discovered during surveillance testing.

5. ISSUES

This section reviews issues associated with safe storage of pits at the Pantex Plant, including issues related to pit surveillance and integrity, containers, and storage facilities. Virtually every pit-related project at Pantex needs improvement in planning, resource loading, and development of a complete and logical set of functions and requirements. Also, many projects have a long-standing dependence on the success of the AT-400A repackaging effort to ensure safety, but the AT-400A project is now being scaled back. This may have broad implications that are not being addressed comprehensively by DOE. In fact, many decisions that affect the continued safe storage of pits at Pantex have been made in an apparently disjointed manner by various elements within DOE.

5.1 PIT SURVEILLANCE AND INTEGRITY

The required scope of the pit surveillance program is closely coupled with the adequacy of pit storage conditions. However, the number of surplus pits sampled for surveillance each year (about 30) is small compared with the thousands of such pits stored at Pantex. Considering the variety of surplus pit types, it will take some time to gather an adequate amount of data to support an informed judgment about all such pits. However, several issues related to pit storage and surveillance can be identified, as detailed in the following sections.

5.1.1 Pit Corrosion

The slow sampling rate at Pantex might be acceptable if the storage conditions were known to be adequate. However, characterization of the condition of surplus pits stored at Pantex began only recently, so the active degradation mechanisms involved and their rates are not well understood for pits stored outside intact nuclear weapons. For example, past inspections, cleaning, or other operations involving pits may have used chemicals with constituents (e.g., halides) that could initiate corrosion of the pit outer metal shell or joint.

Furthermore, the design agencies have concluded that the current pit storage container, the AL-R8, is not suitable for long-term use, for several reasons. The Celotex fiberboard packing material used in the AL-R8 is made from sugar cane, paper, starch, and wax, and can contain significant moisture and more than 0.1 weight percent chlorides. Since the AL-R8 containers are not sealed, the pits inside are also exposed to the humidity of the ambient air. The combination of moisture and chlorides is damaging to many metals, including the beryllium cladding used for some pit types.

The design agencies have determined that galvanic corrosion near welds is a potential degradation mechanism for beryllium cladding in a humid environment, such as that inside an AL-R8. Additionally, inspections by LANL have shown that beryllium pit cladding is subject to pitting corrosion in an aqueous chloride environment. Corrosion could penetrate completely through the cladding. LANL has also shown that pitting reduces the strength and ductility of beryllium test coupons because of the notch sensitivity of beryllium. This in turn could render corroded pits more vulnerable to failure as a result of temperature excursions or mechanical damage. Field experience with actual weapon components has confirmed that beryllium-clad pits are vulnerable to chloride pitting. Based on this information, the design agencies have concluded that the AL-R8 is not suitable for long-term pit storage, and that pits, particularly strategic-reserve pits, need to be removed from contact with Celotex as soon as possible.

The design agencies detailed these problems in letters to DOE-AL on August 22, 1995, and to the Pantex Plant on May 16, 1997. Key assumptions include infrequent pit handling and limited temperature excursions. The recommendations made by the design agencies are as follows:

- No pits should be stored in AL-R8 containers. Strategic-reserve pits should be removed from AL-R8 containers as soon as possible.

- If AL-R8s are used for an extended period (5 years for strategic-reserve pits, 10 years for surplus pits), an aggressive sampling and monitoring program is required, i.e., 100 percent inspection every 5 years.

- Humidity control is needed if strategic-reserve pits will be stored in AL-R8 containers for 5 years or more.

- Shrink-wrapping plastic around the Celotex packing material may be an acceptable interim solution.

Efforts to address the above issues are hindered by the fact that there is no formal project devoted to resolving pit corrosion issues. It was long expected that the AT-400A would be available to resolve corrosion issues in a timely manner, but this now appears unlikely.

Pantex has been working to establish a pit surface characterization laboratory that will provide local capabilities for nondestructively evaluating pit surface topography and chemistry. This laboratory was to include a stereo microscope, white light interferometer, scanning electron microscope, auger electron spectroscope, Fourier transform infrared spectrometer, and x-ray photoelectron spectroscope. Although some equipment has been procured, it is not clear whether funding will be available to finish outfitting the laboratory.

Despite the fact that the first design agency letter on the need for improved pit packaging was sent to DOE-AL in 1995, little was done at Pantex to address pit corrosion concerns until very recently. Funding is problematic, and efforts to characterize or repackage pits at Pantex are resource limited. Moreover, the key design agency participants in pit corrosion evaluations have other duties. As of October 1997, basic tests such as evaluation of the corrosion of chloride-contaminated beryllium in humid air instead of water had not been initiated. Definitive resolution of corrosion and other packaging issues will require augmented efforts and a more formal and integrated approach.

5.1.2 Pit Environmental Controls

The design agencies have recommended maximum allowable storage temperatures for each pit design. The limits for some pits are intended to guard against cladding failure; the limits for other designs are intended to preserve pit quality. The design agencies have stated that storage temperature is particularly important to maintaining the integrity of some non-strategic-reserve pit types (W48, B54, and W55).

Pantex has implemented these safety-related temperature limits in procedures, but the controls are not part of the formal authorization basis for pit storage facilities. There are two reasons for this: (1) MHC is in the preliminary stages of developing authorization basis controls (e.g., TSRs), and (2) MHC assumes that pits involved in accidents will not have been breached beforehand.

The latter assumption leads MHC to the conclusions that little plutonium oxide will be available for immediate release and that accident consequences will not be severe. Typically, these bounding analyses have not addressed scenarios such as pit breaches that may have gone unrecognized for a long period of time. Such breaches could result in continuing generation of plutonium oxides that would be available for release during either normal handling or an accident. The resulting consequences for workers could be significant, particularly if a number of pits have failed.

Given the potential consequences of pit breaches in storage, the implementation of authorization basis controls appears warranted. Doing so would ensure high visibility for any future changes to monitoring, maintenance, or surveillance programs and systems that ensure continued pit integrity and operator safety.

5.1.3 Pit Storage at Other Sites

A large number of pits are presently stored at the Rocky Flats Environmental Technology Site. With the exception of a small number of pits being sent to the design agencies, all pits at Rocky Flats are planned to be shipped to Pantex. The pits will be visually inspected before and after shipment, so gross corrosion or other damage should be detected before the pits join the general inventory at Pantex. If any pits remain at Rocky Flats for an extended period of time, it would be prudent to implement consistent environmental controls and include them in the storage surveillance program (or develop a separate surveillance plan) to ensure that any problems are detected in a timely manner. Likewise, storage and surveillance criteria for the significantly smaller number of pits stored at other sites (e.g., the Savannah River Site and the design agencies) ought to be equivalent to the criteria applied at Pantex.

5.2 PIT CONTAINERS

The container is the next barrier beyond the clad and plays an important safety role. For example, the 1996 Pantex Plant Final Environmental Impact Statement assumes that only a quarter of the pits in a magazine would be affected by an aircraft crash with fuel fire (p. 4-309). The containers limit the number of pits involved in this type of postulated accident. The following subsections describe issues associated with the pit containers that may prevent them from compensating for the weaknesses in pit surveillance programs and environmental controls discussed earlier.

5.2.1 Existing Design Containers

The AL-R8 containers currently provide mechanical and thermal protection, but no confinement since they are unsealed and susceptible to corrosion. Also, the internal Celotex packing is a source of chlorides and moisture, which can accelerate container corrosion. Pit surveillance and other inspection activities have found some AL-R8 containers to be significantly corroded. Many of these carbon steel containers have been poorly preserved. Pantex has determined that up to 3000 AL-R8s were procured without the required corrosion-resistant coating on the inner surface of the carbon steel container.

5.2.2 New Design Containers

The AT-400A pit packaging line at Pantex began operations in August 1997, but only W48 pits are currently planned to be packaged in these containers. B54 pits are strong candidates to succeed the W48s, followed in turn by strategic-reserve pits, but it is not clear what further repackaging will be done or when. If pits are not repackaged expeditiously, Pantex lacks the resources to implement the monitoring program recommended by the design agencies. At the current repackaging rate, it will take more than 2 years to repackage the W48s and would take in excess of 40 years to repackage all the pits now at Pantex.

DOE and MHC are considering replacing the manual AT-400A repackaging line in building 12-99 with a mechanical line. A mechanical line is expected to improve throughput from about 20 pits per month to about 40. At this time, it appears that Pantex is planning to place the new line in the same bays as the existing line. There are at least two potential problems with this choice: (1) DOE and MHC will have lost the opportunity to transfer pit operations to a more appropriate location and reclaim the bays in 12-99, which are some of the most modern and robust at Pantex, for nuclear explosive operations, and (2) the manual line will have to be suspended during installation of the mechanical line, which will further delay repackaging of pits.

5.2.3 Modified Design Containers

Early in 1997, MHC began developing an improved, sealed version of the AL-R8 as an interim solution to resolve the concerns of the design agencies. This effort was narrowly focused on pits being received from Rocky Flats, to avoid later repackaging of these pits and thereby minimize personnel exposure. Extra pit handling would increase cost, risk, and radiation exposure.

The MHC design for an improved AL-R8 would retain the existing internal fixturing, Celotex packing, and external container. The key change would be the addition of a mechanically sealed stainless steel inner vessel filled with an inert gas. The inner vessel would separate the pit from the Celotex. The primary seal would be a copper gasket compressed between the lid and a large flange. A valve would be built into the lid for inerting of the vessel and for future vapor sampling. The gasket, flange, and valve would be industry-standard designs intended for use in high-vacuum applications. MHC and the design agencies believe these seals are more than adequate for interim storage. The main question being addressed is whether the new design has adequate heat transfer to prevent temperature-sensitive pits from overheating under normal storage conditions.

Since May 1997, all three design agencies, as well as DOE-AL, have initiated their own designs (six designs total) for sealed AL-R8 inserts, focusing on the general population of pits. In September 1997, DOE-AL down-selected from these options to three competing designs, one of which is the original MHC concept. DOE was intending to select a single design by early December 1997 but has delayed this decision by two months. In a further complication, Pantex was informed in early October that there is no FY98 funding for the Pantex share of this effort.

All of the designs are based on a set of functions and requirements, assembled by MHC specifically for Rocky Flats pits, that appears to be incomplete for the general pit population. As of September 1997, some recent applicable Safety Analysis Reports, as well as AT-400A design documentation, had not been screened for functions and requirements that might be applicable to the modified AL-R8. Under these conditions, some important container functions and requirements, such as the container's role in protecting pits during postulated on-site transportation accidents, are being neglected or inadequately addressed

Even if an improved AL-R8 is qualified and used for storage at Pantex, there is a distinct possibility that surplus pits will need to be repackaged again in the future. The AL-R8 is no longer certified as an off-site shipping container, and there are no plans to certify an improved AL-R8. Therefore, if surplus pit disposition activities are performed at a site other than Pantex, the pits involved will need to be repackaged in certified shipping containers. The AT-400A was designed to meet all requirements for certification for off-site shipments, but is not yet certified. Another option might be to develop and certify an overpack for a complete AL-R8 or for the new sealed inner vessel, but this is beyond the scope of the current set of requirements for the improved AL-R8.

In summary, as of September 1997, the modified container designs appear to be an improvement compared to the current AL-R8s, but there is no present DOE commitment to pursue any of these improved designs. Also, the current designs are proceeding without complete definition of the requirements. Under these conditions, some important container functions may be neglected. Finally, it does not appear that DOE has thoroughly considered the ramifications of the container modifications for the Pantex authorization basis.

5.3 PIT STORAGE FACILITIES

5.3.1 Zone 4 Magazines

Most pits at Pantex are stored in AL-R8 containers in Zone 4 magazines. Neither the magazines nor the containers provide confinement. Maintaining adequate environmental control of the pits, as discussed earlier, has been a particular concern since most magazines rely on passive cooling.

The capability of Pantex facilities, including the magazines, to mitigate the consequences of an aircraft crash remains an open question. Because of the proximity of Pantex to Amarillo International Airport and to local navigational aids, an aircraft crash into either a Zone 4 magazine or Zone 12 facility is credible, though extremely unlikely (estimated probability is 3×10^{-5} per year).[6] Evaluations to date indicate that an impact by an air carrier or military aircraft could perforate most magazines and facilities. Impacts by smaller, slower aircraft, while not penetrating the walls, could still cause concrete scabbing, showering internal spaces with debris. Although the containers provide some protection, the number of pits likely to be damaged, resulting in a plutonium release, is uncertain. DOE has implemented a corrective action plan to reduce aircraft overflights, although the effectiveness of this program is not yet known. MHC is also evaluating aircraft crash consequences on a site-wide basis.

In recent years, MHC has initiated a magazine temperature monitoring program that has generally been run well. The program has shown that during the summer, pit temperatures can approach the limits specified by the design laboratories for some pits. This has occurred in the past, but the likelihood of recurrence has been reduced for two reasons. First, nearly all of the pits of greatest concern (W48s) are stored in the two air-conditioned magazines. Second, magazine temperature monitoring can be used to detect elevated temperatures, so that corrective actions can be taken before temperature limits are exceeded. Temperatures inside the passively cooled magazines change slowly because of the thermal lag provided by the earth overburden, so there should be adequate time for response. However, the response may involve additional container handling and associated risk.

Currently, there are no authorization basis controls related to controlling pit or magazine temperatures or maintaining active cooling for the two magazines with W48 pits. For at least three pit types, there are identified temperature-related failure modes. The consequences of

[6] DOE/EIS-0225, "Final Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapons Components," Section 4.15, November 1996.

overheating several hundred pits could be significant. As discussed in Section 5.1.2, it would appear appropriate to implement authorization basis controls on pit temperatures.

5.3.2 Special Nuclear Material Component Staging Facility (12-116)

The 12-116 facility has never been used and is undergoing a backfit to accommodate up to 4000 strategic reserve pits. The backfit project has made progress during the last 2 years, but has been subjected to continual changes in the facility's mission, intended inventory, functions and requirements, resources, and work scope.

A recent example is a last-minute change to the backfit work scope to delete pit vault humidity controls and thereby reduce costs. DOE and MHC consider that the humidity controls will not be needed if pits are eventually stored in sealed containers. This decision was made at some risk, because strategic-reserve pits are unlikely to be repackaged soon in sealed containers. The design agencies consider these humidity controls to be quality requirements and not safety requirements for strategic-reserve pits.

Within 12-116, there are systems that appear well engineered, but their specified functions and requirements may not have kept pace with facility changes. An example is the robotic weight and leak check system designed by Sandia National Laboratories for inspecting pits in the current AL-R8 containers. The utility of this system for pits in the long-intended AT-400A containers was never clear. It remains to be seen how this system can be made compatible with a modified AL-R8 design.

As of September 1997, few systems within 12-116 had been designated by MHC as requiring authorization basis controls and safety classification. The pit container staging system is one such safety system that has been missed. It consists basically of stacked pallets, each containing four or six horizontally oriented pit containers. The staging system needs to resist structural loads that could result from a facility accident. It is not clear how the facility would recover if these pallets toppled or collapsed. The role of the staging system in mitigating an accident would be apparent if potential safety systems had been thoroughly screened using the DOE standard approach (DOE-STD-1021-93).

The need to resolve certain open safety questions will limit the facility's pit inventory until post-startup modifications have been completed. Building response to an aircraft crash remains an open question to be addressed in the safety analysis report. Other major open questions include criticality safety, the seismic capacity of the pit staging system, and heat load and temperature variation in the vaults. Some of these open questions are interrelated. For example, criticality analyses assume that the pit staging system would not collapse during an earthquake. MHC plans to qualify a staging system using shake-table test results; however, part of the final staging system may include shelving that is not part of these tests.

In summary, there have been major perturbations in the 12-116 backfit process. These have been caused by uncertainty in inventory, seismic requirements, criticality safety, temperature and humidity controls, AT-400A programmatic direction, resource availability, and backfit work scope. Identification of facility systems that require authorization basis controls and safety classification also remains an open issue.

5.3.3 Prospective Surplus Pit Storage Facility (12-66)

Significant design questions must be addressed for the 12-66 facility before it would be appropriate for use as a pit storage facility. Many of the issues identified above for 12-116 apply also to the 12-66 facility, but on a larger scale because of the larger inventory being placed in a weaker facility.

The 12-66 warehouse is not likely to provide a level of protection comparable to that of other major plutonium facilities in the DOE complex without significant structural modifications or a high reliance on container toughness. For example, 12-66 does not have the thick internal walls of 12-116, which can carry the significant lateral loads that would be common to many externally driven accidents. Also, the 12-66 outer walls are half as thick and have less than half the reinforcement of the outer walls of 12-116. It is unlikely that 12-66 would perform nearly as well as 12-116 during a tornado, aircraft crash, or other major accident.

Whether 12-66 is acceptable as a pit storage facility depends on what functions and requirements it is expected to meet. At this time, no systematic review of other major plutonium storage facilities across the DOE complex has been performed to ensure that a complete and logical set of requirements has been defined. The lack of such a review has resulted in inconsistencies in the effort to date, for example, in safety system selection, assumed accident loads, and structural analysis methods.

Pantex personnel have indicated that reduced accident loads may be considered for this facility's design in the future (i.e., equivalent to those required by the Uniform Building Code for an essential facility, such as a fire station, with no confinement function). In 1996, DOE proposed reduced accident loads for 12-116, based on a revised DOE standard, but MHC ultimately did not use them. The 12-116 proposal was based on bounding accident analyses predicting off-site consequences below evaluation guidelines. However, few accident evaluations have considered the full range of possible consequences to on-site personnel, including those who would respond to a major facility accident. Further information is provided in a previous staff report.[7]

The Zone 12 consolidation appears to be driven by conflicting future scenarios. There will either be so little demand for magazines that Zone 4 can be closed or so much demand that there will be no space in Zone 4 for surplus pits. There are aspects of this relocation that have not been clearly addressed in the decision-making process.

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[7] Keilers (Board staff) memorandum to G. W. Cunningham (Board Technical Director), December 2, 1996.

Regardless, it appears that adequate safety evaluations were not available to support the DOE decision to move surplus pits from Zone 4 magazines to 12-66. For example, the storage and disposition PEIS includes a section on facility accidents at Pantex (PEIS, Appendix M), but this was not a comprehensive safety evaluation. In fact, key accident scenarios described in that document apply only to containers and facilities that exist at other sites and not at Pantex. There appears to have been no MHC-sponsored safety analysis prior to a hazard analysis completed in August 1997 by Westinghouse Savannah River Company. Several externally driven accident scenarios, such as an aircraft crash or an earthquake, need to be addressed further.

Based on the above observations, it is not yet apparent that moving pits out of magazines and into 12-66 represents a net safety improvement. Building 12-66 does have advantages, such as proximity to pit facilities and active cooling for temperature-restricted pits. However, the Zone 4 magazines also have advantages, such as a lower accident source term for single-magazine events, better-understood criticality safety, and possibly better thermal performance (particularly if the magazines are backfit with active cooling or if temperature-sensitive pits are removed). Improved, sealed containers could provide secondary confinement in both cases.

6. CONCLUSIONS

From a safety standpoint, the pit storage system at Pantex ought to be considered as a combination of interrelated barriers to radioactive release, as well as the associated controls needed to maintain those barriers. A change in one barrier or control will affect the others and can be appropriately addressed only through an integrated systems approach.

Since 1989, a number of questions related to continued safe storage of pits have been raised. In 1992, DOE initiated several proactive programs to ensure continued safe pit storage. The most successful of these programs resulted in relocation of nearly all the W48 pits (the type of most concern) to temperature-controlled magazines. In August 1997, MHC began repackaging the W48 pits into the best containers available, the AT-400A, albeit at a very slow rate.

However, other deficiencies in the overall pit storage system (i.e., the clad, containers, and facilities) have never been fully addressed, and recent activities appear to achieve short-term goals and cost reductions without fully considering the long-term implications for pit storage. Some of the issues that result from this situation are as follows:

- For most pits, the clad is the only reliable confinement, but resolution of clad corrosion issues is hindered by a lack of resources and of a formal project to understand failure mechanisms and identify corrective actions.

- The storage surveillance program is aimed at evaluating the condition of pits stored at Pantex. However, the number of pits sampled for surveillance each year is small compared with the thousands of pits stored at Pantex and is not statistically based.

- The lack of authorization basis controls for pit storage temperatures renders at least three pit designs vulnerable to cladding failure. Pantex has implemented temperature limits identified as safety related by the design agencies, but these controls are not enforced by the authorization basis.

- The most commonly used pit storage containers (the AL-R8s) contribute to, rather than mitigate, the above concerns with the pit clad. For years, DOE has indicated that all the pits would be repackaged in new containers, the AT-400A, that would prevent pit corrosion, improve accident mitigation, and compensate for the lack of authorization basis controls related to pit integrity. DOE no longer appears committed to repackaging of pits other than the W48s in these containers.

- To compensate for scaleback of the AT-400A, efforts have been initiated to design improved containers; however, these efforts appear confused and lack complete requirements and a formal DOE programmatic commitment.

- The planned changes in pit storage facilities appear unlikely to compensate for the above weaknesses in the surveillance program, authorization basis controls, and containers. In particular, the proposed transfer of pit storage from Zone 4 to Zone 12 will not clearly result in a net safety improvement.

- Although the strategic reserve facility (12-116) appears robust, the surplus pit storage facility (12-66) may require either significant structural modifications or a high reliance on container toughness. A systematic review of other major plutonium storage facilities may be worthwhile to ensure that a complete and logical set of design requirements has been defined.

Many of the issues discussed in this report can be addressed only by applying a systems approach and comprehensively considering the interrelationships among the barriers to release and the programs and controls needed to maintain them.

APPENDIX

COMPONENT STAGING FACILITY (12-116) DESIGN CRITERIA

In general, the structural design criteria for the 12-116 facility were equivalent to or more rigorous than recent DOE requirements for natural phenomena hazards mitigation (DOE Order 5480.28). DOE defines required structural performance in terms of performance category (PC), which basically is a measure of the annual probability of unacceptable behavior during an accident. Facility structures at different sites may be assigned the same performance category (e.g., PC-3), but then be designed to different accident loads based on the site-specific probability of each hazard. For example, Pantex is susceptible to more severe winds/tornadoes but a less severe earthquake than the Nevada Test Site (NTS). As a result, the same PC-3 facility located at Pantex and at NTS would be required to withstand different winds (132 and 87 mph, respectively) and different seismic accelerations (0.13 and 0.34 pga, respectively) to achieve similar probabilities of unacceptable behavior during an accident.

Table 1 compares some specific 12-116 criteria with DOE requirements for reactors (PC-4) and for major plutonium facilities (PC-3). The assumed tornadic wind would result in a pressure on the building nearly twice as great as DOE would now stipulate for a reactor if one were sited at Pantex. Also, the original suite of design tornadic missiles includes automobile and timber missiles that are factors of 1.3 and 4, respectively, more energetic than would be stipulated for a reactor. The assumed seismic event is less than specified for a reactor, but comparable to that now specified for a major plutonium facility at Pantex.

Table 1. Comparison of 12-116 Design Criteria with Current DOE Criteria

Pantex Criteria	12-116 (original)	PC-3	PC-4
Seismic acceleration	0.14 pga	0.13 pga	0.21 pga
Tornadic wind	250 mph	132 mph	182 mph
Tornadic missile	139 lb timber (4 x 12") @ 100 mph	15 lb timber (2 x 4") @ 100 mph H & 70 mph V	15 lb timber (2 x 4") @ 150 mph H & 100 mph V
		75 lb (3") pipe @ 50 mph H & 35 mph V	75 lb (3") pipe @ 75 mph H & 50 mph V
	4000 lb automobile @ 25 mph		3000 lb automobile @ 25 mph
Pressure change	1.13 psi @ 0.41 psi/s	0.28 psi @ 0.14 psi/s	0.87 psi @ 0.35 psi/s