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APPENDIX A
INTEGRATED HAZARD ANALYSIS

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Revision 1

FERNALD
Environmental Management Project

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ACRONYMS

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
FAT&LC	Fernald Atomic Workers and Labor Council
FCP	Fernald Closure Project
FMPC	Feed Materials Production Center
IHA	Integrated Hazard Analysis
MRS	Mechanical Retrieval System
NHASP	Nuclear Health and Safety Plan
OS&H	Occupational Safety and Health
OU	operable unit
PHAR	Preliminary Hazard Analysis Report
PRS	Pneumatic Retrieval System
RMRS	Rocky Mountain Remediation Services
S&M	Surveillance and Maintenance
SSC	structures, systems, and components
WSA	Waste Storage Area

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EXECUTIVE SUMMARY

This Integrated Hazard Analysis (IHA) report forms the basis for the development of the HASP, which contains hazard analyses and facility hazard categorization in accordance with DOE-STD-3009-94. The IHA is a qualitative analytical tool usually performed early in the life of a project to systematically identify, collect, and integrate information on health and safety issues concerning:

- identification of hazards (materials in quantity, form, and location);
- energy sources, potential initiating events, causes of hazardous conditions;
- consequences of hazardous events without preventive/mitigative measures;
- preventive/mitigative measures;
- frequency of occurrence of events (credibility of consequences);
- severity of consequences of events; and
- significance of hazards (risk, real and perceived).

This IHA contains tables that summarize the hazards of various tasks and subtasks within the Silo 3 Project. To ensure that the hazards considered are all inclusive, an IHA workshop was held in June 2001 with staff from Fluor Fernald, Inc., and Jacobs Engineering Group – representing engineering, project management, and all health and safety disciplines, as well as union technicians. The health and safety hazards were reevaluated at this workshop to identify all possible hazards that may be encountered within the Silo 3 Project.

All types of hazards were considered and documented, including standard industrial hazards, human capability limitations, health hazards, electrical hazards, energy-release hazards, radiological hazards, biological hazards, toxic and hazardous materials, and natural phenomena. The results of the analysis are presented in the tables in this IHA. All of the activities were analyzed against a master list of hazards to decide which were potentially applicable.

The identified hazards were entered into the Final Hazard Assessment Table along with possible causes, potential consequences, and estimated frequency and severity on the basis of experience and judgment. Controls and mitigators for all hazards were identified. This information was then used to identify safety hazards that require special attention and/or additional analysis.

The methodology described in Section A.3.0 was used to assess the project hazards. All the potential hazards were anticipated or unlikely accidents with very low consequences. The following exceptions are significant hazards that require further analysis:

- Structural failure of silo due to a dropped load, excessive load, or earthquake

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- Hose rupture during pneumatic retrieval
- Silo wall failure due to wall cutting operations
- Spill material due to a conveyor failure
- Breach of a material storage bag
- Dust collector failure
- Silo depressurization and collapse
- Spill of ferrous sulfate
- Spill contents from a cargo container

The frequency and severity of the standard industrial hazards are not specified in the Final Hazard Assessment Table, which is consistent with the *Hazard Analysis Report for Operable Unit 4 (OU4)*, Appendix B. However, some standard industrial hazards with unlikely frequency may have significant consequences and these hazards warrant some additional consideration. Electrical energy, confined space, and potential energy or elevation hazards have an unlikely frequency and moderately severe consequences, including the possibility of death. The consequence of contact with electrical sources may be a fatal electrocution. The consequence of working in a confined space may be a fatal asphyxiation. The consequence of working at elevated heights may be a fatal fall.

Minor accidents may be expected to occur during the life of the Silo 3 Project. A strong, comprehensive health and safety program has been established to minimize the actual frequency of such accidents.

A.1.0 INTRODUCTION

The purpose of this Integrated Hazard Analysis (IHA) is to provide an integrated identification and qualitative analysis of the hazards associated with the Silo 3 Project. This IHA forms the basis for the development of the Nuclear Health and Safety Plan (NHASP), which contains hazard analyses and facility hazard categorization in accordance with U.S. Department of Energy (DOE) Standard DOE-STD-3009-94 (Ref. 1).

The IHA is a qualitative analytical tool usually performed early in the life of a project to systematically identify, collect, and integrate information on health and safety issues concerning:

- identification of hazards (materials in quantity, form, and location);
- energy sources, potential initiating events, causes of hazardous conditions;
- consequences of hazardous events without preventive/mitigative measures;
- preventive/mitigative measures;
- frequency of occurrence of events (credibility of consequences);
- severity of consequences of events; and
- significance of hazards (risk, real and perceived).

The initial activity required by Procedure NS-0003, *Safety Assessment Hazard Screening and Classification* (Ref. 2), is an IHA workshop, which was conducted June 26, 2001. The results of the IHA workshop are incorporated into this IHA.

The IHA workshop involved a multidisciplinary team that consisted of approximately 25 individuals from Jacobs and Fluor Fernald, Inc. The disciplines represented were engineering, occupational safety and health (OS&H), radiological control, industrial hygiene, operations, construction, and waste management. In addition, the Fernald Atomic Workers and Labor Council (FAT&LC) was represented.

The roster of IHA Workshop participants is as follows: 4998

Name	Title or Discipline
Fluor Fernald, Inc.	
Joel Bradburne	Silos Operations Manager
G. Burleson	FAT&LC, Maintenance Pipefitter
Greg Cantwell	Hoisting & Rigging Manager
Tom Crawford	Silo 3 Project Engineering Lead
Joseph Dickey	Radiological Control Supervisor
Doris Edwards	Silos Construction
James Ellis	Silos Operations
Claude Griffin	Silos Engineering
Barry Ko	Silos Industrial Hygiene
Scott Manley	Silos OS&H
Charles D. Nelson	Silos Safety and Health (Rad/SafetyAnalysis)
Allen Neiling	Nuclear Material Disposition
Tom Shiner	Silos Engineering (Structural)
Charles Shouse	FAT&LC Millwright
George F. Riegelsberger	FAT&LC Maintenance Electrician
LaVon Rutherford	Silos Health & Safety (OS&H/Safety Analysis)
Karen Wintz	Silo 3 Project Manager
Todd M. Valli	Silos Industrial Hygiene
Jacobs	
Jeff Carmony	Instrumentation & Controls Engineer
Glen Schmidt	Process Engineer
Bob Lenyk	Jacobs Project Manager
Andy Stephansen	Lead Structural Engineer
Craig Smith	Lead Mechanical Engineer
Bob Sterling	Piping Lead Engineer

A.1.1 SCOPE

The scope of activities included within this IHA includes the continued storage, surveillance and maintenance (S&M), construction, operation, maintenance, and demobilization of the Silo 3 Project. Approximately 5,088 yd^3 of byproduct metal oxide material stored in Silo 3 will be removed, treated, packaged, and transported to an off-site facility for treatment and/or disposal. Access and retrieval will be accomplished by both pneumatic and mechanical systems. The material will be transferred to a Process Building where the material will be fed into storage bags. Hazards associated with all activities in the Silo 3 Facility are addressed and analyzed in this IHA.

A.1.2 DESCRIPTION OF DOCUMENTATION

This IHA is organized into 8 major sections, similar to the format of the *Hazards Analysis Report for Operable Unit 4 (OU4) Silos,* Appendix B, Integrated Hazard Analysis (Ref. 3).

This introduction is followed by Section A.2.0, which provides background information on the Fernald silos and a description of the Silo 3 Project. The description incorporates by reference the system design descriptions detailed in the *Process Description for the Silo 3 Project* (Ref. 4). These detailed descriptions provide the basis for identifying hazards that can occur at any step of the storage, S&M, construction, operation, maintenance, or demobilization of the Silo 3 Project. Section A.3.0 provides the methods used in performing the final integrated hazard analysis, and Section A.3.1 delineates the tasks and subtasks of the Silo 3 and presents the final integrated hazard analysis table. Section A.5.0 includes the conclusions of the final integrated hazard analysis, the hazards of concern, and the resolutions of these concerns. Section A.6.0 contains the references.

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A.2.0 PROJECT DESCRIPTION

From 1952 until 1989, the Fernald site provided high-purity uranium metal products to support U.S. defense programs. Uranium production halted in 1989 because of declining demand and a recognized need to commit available resources to environmental remediation. Former uranium operations at the site were limited to a fenced 136-acre tract of land known as the Production Area located near the center of the site. Large quantities of liquid and solid wastes were generated by the various production operations at the site. Before 1984, solid and slurried wastes from processes were stored or disposed of in the Waste Storage Area (WSA). This area, located west of the production facilities, includes six low-level radioactive waste storage pits, two concrete silos with earthen berms containing K-65 residues, one concrete silo containing metal oxides, one unused concrete silo, two lime sludge ponds, a burn pit, a clearwell, and a solid waste landfill. The WSA is addressed under OUs 1, 2, and 4. The former Production Area and WSA are fenced and closed to the general public. The remaining areas consist of forest and pasture lands (Ref. 5).

Silo 3 was constructed for the transfer and storage of "cold" 11(e) 2 uranium processing byproduct material (as designated by the Atomic Energy Act) generated through refinery operations at the Feed Materials Production Center (FMPC), now known as the Fernald Closure Project (FCP). The Silo 3 material is a byproduct of uranium ore concentrate processing. The ore concentrates had been preprocessed through a uranium mill where a significant portion of the ^{226}Ra and the gamma-emitting progeny were removed, and thus they were termed "cold" feed material. Silo 3 received metal oxide raffinates generated by all FMPC refinery operations from May 1954 until late 1957.

A.2.1 SILO 3 FACILITY

Silo 3 was constructed in 1952 and is located south of the Waste Pit Area of the FCP property. Silo 3 is a freestanding, pre-stressed concrete, domed silo approximately 80 feet in diameter and approximately 25 feet above ground level (vertical wall). The floor system is constructed of approximately 17 inches of compacted clay, a 2-inch-thick layer of asphaltic concrete, and an 8-inch layer of gravel topped by 4 inches of concrete. Silo 3 has no under drain system. The domed roof tapers from 8 inches thick at the silo walls to 4 inches thick at the apex. The apex is 36 feet high. Increased reinforcing around the dome periphery (ring beam) is provided to support the additional loading from the pneumatic transfer system that has since been removed.

The Remedial Investigation conducted for Silo 3 (Ref. 5) reveals that the silo contains approximately 5,088 yd^3 of residue. Based on an estimated in situ material density ranging from 29 to 58 pounds per cubic foot (lb/ft^3), the available silo material weighs approximately 3,925 tons.

The physical composition of the Silo 3 waste, based on process knowledge and visual observations, is:

- potentially dry, loose, or fine powder at the top;
- compacted powder towards the central and lower portions; and
- potentially water-saturated powder at bottom (approximately 1 ft).

On December 20, 1991, a project was initiated to ensure that all penetrations through the Silo 3 dome were covered and sealed. Removal of the dust collector and permanent sealing of all obvious open pathways was completed January 8, 1992.

A.2.2 SILO 3 STRUCTURAL INTEGRITY

Past safety analyses have recognized that the greatest risk from Silo 3 projects involves the catastrophic failure of the structure. Therefore, structural analyses have been performed to determine the probability of failure and to derive controls necessary to ensure that structural integrity is not compromised during project activities. Three such evaluations have been performed on the structural integrity of Silo 3. These analyses are (1) *Metal Oxide and Empty Silo Study & Evaluation Report* (1986) (Ref. 6); (2) *Silo 1 through 4 Structural Integrity Determination* (1994) (Ref. 7); and (3) a 1998 Engineering Evaluation, *Silo Dome Design Properties* (Ref. 8).

1986 Camargo Report

Camargo Associates, Limited (CAL), in association with Muenow and Associates and Soil & Materials Engineers, Inc., was retained to provide inspection, testing, and evaluation of Silo 3. The evaluation resulted in a report entitled *Metal Oxide and Empty Silo Study & Evaluation Report* (1986). The 1986 report addressed:

- Finite-element structural analysis using as-designed drawings and static loads,
- Field work: soil exploration, pulse-echo testing, and ground-radar survey, and
- Structural analysis based on field data: static, tornado and earthquake loads by dynamic analysis.

The 1986 Camargo Report documented the following findings:

- The Silo 3 dome was in good condition. Irregularities found in the concrete thickness seemed to be related to construction tolerances and not due to deterioration. Some cracking had occurred on the dome surface, but did not limit its capacity.
- The Silo 3 walls were in good condition, but there were a few areas of deterioration. Most of the deterioration was found in the post-tensioning wires, allowing moisture to corrode the wires. While the surface gunite and concrete showed signs of cracking, there was no indication that the cracks penetrated through the silo walls.

- The base slab was in good condition, but it had experienced some random areas of cracking and deterioration. The cracking would be indicative of the aging of the silo due to the freeze-thaw cycle.
- The dome is the critical element under tornado loading. Significant tensile stresses would develop and cracking would occur in the concrete. Under induced earthquake load, the dome is again the critical element. Large shear stresses and displacements would cause in the concrete; however, the silos are expected to remain standing after either event.

Silo 3 should remain serviceable for about 20 additional years (i.e., until about 2006). The surfaces should be sealed against the elements to prevent further deterioration of the post-tensioning wires and to prevent water from entering cracks.

The 1994 Parsons Analysis

Parsons Engineering was retained to perform finite element analysis to determine the structural integrity of the silo walls and domes using 1993 nondestructive testing (NDT) results obtained by Muenow & Associates. The evaluation resulted in a report entitled *Silo 1 through 4 Structural Integrity Determination* (1994). The 1994 report:

- Compared the 1986 and 1993 NDT results; and
- Determined the structural integrity of Silo 3 based on the 1993 NDT data, and the design criteria and loadings per DOE Order 64301A for a "low hazard facility"

The 1994 report concludes that the stresses (compressive and tensile) in the dome and walls are within allowable stress limits. The report also concludes that the 1993 NDT data indicate that the structural condition of Silo 3 is generally "better" than that concluded from the 1986 NDT data.

The 1998 Structural Analysis

Fluor Fernald, Inc. performed an engineering study to determine the physical condition of the OU4 silos, including Silo 3, and to establish load limits for the final OU4 Hazard Analysis Report (HAR). The available structural data was evaluated and the safe load limits were verified for the silo dome. The evaluation is documented in *Silo Dome Design Properties* (Ref. 8).

The study concludes that no quantitative evaluation can be made of silo life expectancy or structural integrity without significant uncertainties. The 1986 NDT data showed a wide variation in the measurements taken. Although the 1993 NDT results had less variability than the 1986 results, they do not confirm the 1986 results in many areas. The physical test programs in 1990 and 1997 showed a wide variability of the compression test results; therefore, no clear structural basis can be rendered.

Petrographic examinations confirm poor concrete quality, presence of extensive cracking, and damage due to freeze-thaw and alkali-aggregate reaction; however, based on the fact that samples were cut and polished for petrographic examination, the material must have some inherent strength. American Petrographic Services indicated that the concrete

prepared for petrographic examination exhibited a concrete compressive strength of at least 3000 psi.

The inherent strength of the in situ concrete can be estimated to be no less than 3000 psi. Its ability to resist loading may be impaired by the extensive micro cracking, planal cracks and potential de-lamination. Any attempt to predict the Silo 3 dome performance must take into account the discontinuity in the load created by this cracking. Due to the data variability and the difficulty in retrieving appropriate samples, further NDT or physical testing will not be useful in generating a precise status of the actual in-situ concrete condition.

The evaluation results provide a basis for determining a silo dome safe load limit. Reference 8 evaluates the safe load limit using the existing structural integrity data, a live load of 700 pounds, and an assumed concrete compressive strength of 2000 pounds per square inch. Three modes of failure were investigated: 1) direct shear or punch through; 2) overall buckling; and 3) local concrete failure. The critical failure mode is a local concrete failure due to tensile flexural loads introduced to the dome by a local concentrated load. It was determined that the silo dome has a capacity to resist a 700 pound live load spread out over a circular area no less than three feet in diameter.

A.2.3 DESCRIPTION OF THE SILO 3 PROJECT

Access and retrieval of the Silo 3 material will be accomplished by both pneumatic and mechanical systems (Ref. 9). Before retrieval, radon concentrations in the silo headspace will be reduced to acceptable levels, by venting through the Silo 3 stack.

Pneumatic retrieval involves vacuuming material, e.g., through openings in the Silo 3 dome. As a part of dome retrieval, the Pneumatic Retrieval System (PRS) is used to remove material behind the silo wall before creating the wall opening. The PRS then transfers material to the Process Building. These activities are referred to as "Phase 1" of the retrieval process.

In addition to pneumatic retrieval, a Mechanical Retrieval System (MRS) is used to access and remove the compacted material from Silo 3. In preparation for mechanical retrieval, a reinforced concrete framework will be installed on the silo wall, and a section of the silo wall will be removed. A mechanical excavator transfers Silo 3 material to a bin located in the Excavator Room. Conveyors feed the material to the adjacent Process Building. These activities are referred to as "Phase 2" of the retrieval process.

A Feed Conveyor, located in the Process Building, receives Silo 3 material from the PRS or the MRS. The Feed Conveyor discharges material to 2 Package Loading Stands. The material will be conditioned by the addition of a binding agent for dust control and stabilization. The binding agent is a ferrous sulfate and sodium lignosulfonate solution that will be sprayed into the fill chutes. Each of the two Package Loading Stands is a semi-automated system with loading spouts, loading stands, thumper tables, weighing scales, and motorized roller conveyors for transporting the filled bags away from the station.

After the bag is filled and closed, the bag assembly is moved to the Package Staging Conveyor. Labeled bags are then transported to the Cargo Container Bay. Bags are transferred into cargo containers using the bridge crane. Once a cargo container is loaded with bags and the lid is replaced, a heavy-duty forklift transports the cargo container to a staging area.

An Interim Storage Area was constructed east of Silo 3 in the year 2000, which is a 1-acre, 9-inch-thick reinforced concrete pad. The pad was constructed to provide interim waste container storage prior to off-site shipment. A portion of this pad is now designated as the site for the Process Building. The pad has catch basins, an underground storm water drainage system, and aprons to the new infrastructure road. Modifications to the pad are required to support the current building requirements.

A.2.4 SAFETY BASIS HISTORY AND UPDATE

Hazard and accident analyses are performed to identify specific controls and improvements that feed back into overall safety management. Consequence estimates form the bases for grading the level of detail and control needed in specific programs. The result is safety basis documentation that emphasizes controls needed to maintain safe operation of a facility. The consequences are classified by the following hazard categories (HCs):

- HC1 – the hazard analysis shows the potential for significant offsite consequences.
- HC2 – the hazard analysis shows the potential for significant onsite consequences.
- HC3 – the hazard analysis shows the potential for only significant localized consequences.

A radiological facility is a facility that does not exceed the HC3 criteria but still contains some quantity of radioactive material. The safety basis documentation requirements for each HC are defined in DOE-STD-3009-94 (Ref. 1).

Fluor Fernald, Inc. has been responsible for maintaining a single integrated safety basis for all activities in OU4 (Ref. 10). Safety programs addressing DOE-STD-3009-94 (Ref. 1), Chapters 6–17, were established and implemented accordingly.

In April 1994, FEMP-2337, Preliminary Safety Analysis Report of Operable Unit 4 (PHAR) (Ref. 11) assigned a preliminary hazard categorization of HC2 to the Silo 3 segment based on a comparison of hazardous material inventory to the values in DOE-STD-1027-92, and a final hazard categorization of HC3, based on hazards analysis. The hazards analysis that resulted in this final categorization of HC3 was based on the proposed design, inventory of hazardous materials in the segments, and safety analyses including bounding consequence accident scenarios. These bounding accident scenarios were the result of silo failure that released and dispersed up to 1 percent of the total Silo 3 inventory. Initiating events included Natural Phenomena and man-made events such as crane failure or truck impact.

A subsequent review of the calculations supporting the PHAR revealed that highly-conservative assumptions were used to predict the consequences. Fluor Fernald, Inc., reevaluated the hazard category calculation that considers the bounding accident identified

in the PHAR. This calculation documented as SA-CALC-052, *Silo 3 Earthquake Evaluation using DOE-STD-1027-92 Meteorological Conditions* (Ref. 13), shows that the radiological dose consequence from an earthquake does not present the potential for significant localized consequence for Silo 3 in its current storage configuration, and therefore the dose consequence is below the HC3 dose threshold. The appropriate hazard categorization for the existing Silo 3 storage configuration is as a Radiological Facility.

Fluor Fernald, Inc. has directed the preparation of a NHASP to document hazards identification, hazard categorization, and accident analysis, as defined in 10 *Code of Federal Regulations* (CFR) 830 and consistent with the technical position NTSP-2002, Methodology for Final Characterization for Nuclear Facilities from Category 3 to Radiological issued in 2002 by DOE-EH-53, Office of Nuclear Safety. This paper clarifies DOE-STD-1027 final hazard categorization and applies the methodology to classification below HC-3. This IHA has been prepared to support the NHASP for the Silo 3 operation, maintenance, and demobilization activities.

A.3.0 METHODOLOGY

This IHA summarizes the hazards of various tasks and subtasks within the Silo 3 Project. The summary tables are presented in Section A.4.0 and are labeled as final integrated hazard analysis because they were assessed while the project and activities were in their final stages of design. To ensure that the hazards considered are all-inclusive, subsequent reviews were completed by staff from Fluor Fernald, Inc., and Jacobs representing engineering, project management, and all health and safety disciplines. The health and safety hazards were evaluated to identify all possible hazards that may be encountered within the Silo 3 Project. Additional hazards have been added to the final integrated hazard analysis tables. The final integrated hazard analysis tables have been based on those submitted with the conceptual design and supplemented by the hazards identified during design reviews.

The final integrated hazard analysis processes contained herein are in compliance with the recommended process in Fluor Fernald, Inc., Procedure NS-0003, *Safety Assessment Hazard Screening and Classification* (Ref. 2). Further information on the process and many other hazard evaluation procedures can be found in *Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples* (Ref. 16). This IHA will be integrated into the final, formally approved safety basis documentation for the Silo 3 Project.

A.3.1 HAZARD IDENTIFICATION

All types of hazards were considered and documented, including standard industrial hazards, human capability limitations, health hazards, electrical, energy-release, radiological, biological, toxic and hazardous materials, and natural phenomena. All of the activities were analyzed against a master list of hazards, Table A.3.1, to decide which were applicable (Ref. 16). The results of the analysis are presented in this IHA.

The identified hazards were entered into the final integrated hazard analysis tables along with possible causes, potential consequences, and estimated frequency and severity, on the basis of experience and judgment. Controls and mitigators for all hazards were identified. This information was then used to identify safety hazards that require special attention and/or additional analysis. Table A.3.2 contains the criteria for significant hazards as defined in NS-0003, *Safety Assessment Hazard Screening and Classification* (Ref. 2). Table A.3.3 provides the consequence classifications employed for this final integrated hazard analysis. These consequence classifications were selected for inclusion in the final integrated hazard analysis tables under the heading of "severity."

Table A.3.1. Hazard Identification Checklist

Item	Hazard	Definition	Potential Accident/Effect
1	Acceleration/ Impact	Change in velocity, impact energy of vehicles, components or fluids	1. Structural deformation 2. Breakage by impact 3. Displacement of part or piping 4. Seating or unseating of valves or electrical contacts 5. Loss of fluid pressure head (cavitation) 6. Pressure surges 7. Explosions or detonations
2	Potential Energy/ Elevation	Potential to fall	1. Falling of individuals from elevated locations 2. Falling of elevated objects, striking and injuring people, or damaging structures or equipment 3. Falling attributable to lack of handrails/ladder enclosures that could prevent falls
3	Chemical Energy/ Reactivity	Chemical reactions	1. Fire 2. Explosion/detonation 3. Exothermic reactions 4. Production of toxic/flammable gases
4	Contamination	Introduction of contamination	1. Clogging of mechanical components 2. Friction between moving parts 3. Component degradation 4. Making equipment/structures/ components unusable because of contamination
5	Electrical Energy	Electrical component release or failure, shock	1. Electrocution 2. Involuntary personnel reaction 3. Personnel burns 4. Ignition of combustibles 5. Inadvertent activation of equipment 6. Disabling of electric emergency/safety equipment 7. Interruption of communications
6	Human Capability	Human factors	1. Personnel injury due to lifting too much or improper lifting 2. Personnel injury because of: a. Restricted/excessive hours b. Hazardous location c. Inadequate visual/audible warnings 3. Equipment damage by improper operation because of: a. Inadequate training b. Inaccessible control c. Inadequate control display/identification d. Inadequate procedures
7	Interface Interaction	Compatibility between systems/ subsystems	1. Incompatible materials reaction 2. Interfacing reactions 3. Unintended operations caused by software

Table A.3.1. Hazard Identification Checklist

Item	Hazard	Definition	Potential Accident/Effect
8	Human Hazards	Conditions that can cause human injury	1. Personnel injury because of: a. Sharp edges/corners b. Limited work area 2. Damaged walking/working surfaces that can cause tripping injuries 3. Unguarded equipment
9	Kinetic Energy	System/component linear or rotary motion	1. Linear impact 2. Disintegration of rotating components
10	Material Deformation	Degradation of material by corrosion, aging, embrittlement, or oxidation	1. Change in physical or chemical properties 2. Structural failure 3. Electrical insulation breakdown 4. Erosion of lines or components 5. Component failures 6. Collapse/loss of containment
11	Mechanical Energy	System/component energy	1. Personnel injury/equipment damage from energy release of component such as a spring 2. Personnel injury because of being caught/crushed by moving parts
12	Natural Phenomena	Lightning, high winds, projectiles, earthquakes, floods, tornadoes	1. Structural damage from wind/tornadoes 2. Collapse and loss of containment from earthquakes, wind and tornadoes 3. Electric discharge 4. Dimensional changes from solar heating 5. Personnel injury/death from projectiles 6. Equipment/structural damage from projectiles 7. Personnel injuries/death from flooding 8. Equipment/structural damage from flooding 9. Damage and injuries because of lightning
13	Pressure	System/component energized by high, low, or changing pressure	1. Fragments/noise and pressure pulse from over-pressurized container rupture 2. Line/hose whipping 3. Container implosion 4. System leaks 5. Aeroembolism, bends, choking or shock 6. Deformation because of stress failure
14	Radiation	Radiation exposure and conditions including electro-magnetic, ionizing, thermal, or ultraviolet radiation	1. External exposure 2. Contamination of personnel, equipment, and/or facilities 3. Radon exposure 4. Internal exposure

Table A.3.1. Hazard Identification Checklist

Item	Hazard	Definition	Potential Accident/Effect
15	Thermal	High and low and changing temperature	1. Ignition of combustibles 2. Initiation of other reactions 3. Distortion of parts 4. Expansion/contraction of fluids and solids 5. Liquid compound stratification 6. Personnel injury/stress
16	Toxicants	Adverse human effects of inhalants or ingestation, and adverse effects on biota	1. Respiratory system damage 2. Blood system damage 3. Body organ damage 4. Skin irritation or damage 5. Nervous system effects
17	Biohazards	Adverse human effects	1. Insect sting/bites 2. Histoplasmosis 3. Snake bites
18	Vibration/ Sound	System-/ Component-produced energy	1. Material fatigue 2. Personnel fatigue or injury 3. Pressure/shock wave effects 4. Loosening of parts 5. Chattering of valves or contacts 6. Communication interference 7. Impairment or failure of displays 8. Hearing loss, both acute and long-term
19	Caustic/Acidic	Chemical reactions because of chemical energy	1. Burns 2. Chemical reactions
20	Spill/Loss of Containment	Release of hazardous materials	1. Personnel injury 2. Costly cleanup 3. Damage to components/property 4. Off-site transport of contaminant 5. Environmental or ecosystem damage
21	Industrial/ Construction Hazards	Hazards encountered in industrial work environments, such as confined spaces or welding	1. Personnel injury/death 2. Loss of work/production

Table A.3.2. Criteria for Significant Hazards

		Hazard Consequence			
Frequency		**Very Low**	**Low**	**Moderate**	**High**
Anticipated	$\geq 10^{-2}$/yr				
Unlikely	$\geq 10^{-4}$/yr but $< 10^{-2}$/yr				
Extremely unlikely	$\geq 10^{-6}$/yr but $< 10^{-4}$/yr				
Incredible	$< 10^{-6}$/yr				

The crosshatched areas of the table indicate frequencies and hazard consequences that are considered significant and require analysis.

Table A.3.3. Consequence Classification

	Worker Safety[a]	Worker Radiation Exposure	Worker Chemical Exposure[b]	Public Radiation Exposure	Public Chemical Exposure[b,c]	Public Safety
High	Fatalities and/or numerous serious injuries	> 250 rem	ERPG-3	>25 rem	ERPG-2	> 5 serious injuries
Moderate	1 fatality or > 5 serious injuries	> 5 but < 250 rem	ERPG-2	> 0.5 but < 25 rem	ERPG-1	> 1 but < 5 serious injuries
Low	> 1 but < 5 serious injuries	> 0.5 but < 5 rem	ERPG-1	> 0.01 but < 0.5 rem	PEL-TWA[d]	Minor injury
Very Low	Minor injuries	< 0.5 rem	< ERPG-1	< 0.01 rem and other legal limits on normal emissions	EPA[e] and other legal limits on normal emissions	

[a] For the purposes of this table, a serious injury is defined as one that results in lost time.
[b] Emergency Response Planning Guidelines (ERPG) (Ref. 17).
[c] Threshold Limit Values for Chemical and Physical Agents and Biological Exposure Indices, American Conference of Governmental Industrial Hygienists (Ref. 18).
[d] PEL – TWA = permissible exposure level – time-weighted average
[e] EPA = U.S. Environmental Protections Agency

A.3.2 SILO 3 TASKS AND SUBTASKS

The Silo 3 Project tasks and subtasks were defined to provide a logical organization as a function of time and to eliminate redundancy in the final integrated hazard analysis table. The tasks include construction, operation and maintenance, and demobilization. The operation and maintenance tasks were divided into subtasks for each major function of the Silo 3 Project. This feature in the organization eliminates the redundancy in the final integrated hazard analysis tables by negating the need to repeat hazards for each task.

Table A.3.4 is a matrix of tasks and subtasks versus hazard types for the Silo 3 Project. The tasks and subtasks described above comprise one axis of the matrix, while the hazard types comprise the other axis. Numbers and letters are entered into the matrix to designate specific hazards that are addressed in the final integrated hazard analysis (Table A.4.1). The matrix assists in ensuring that each hazard type is correctly recognized and addressed in the final integrated hazard analysis and in ensuring that the hazards are identified for each task.

The hazards were derived from Table A.3.1, the Hazard Identification Checklist, which defines 21 types of hazards according to physical, chemical, and biological properties (Ref. 16). Each of these hazard types was addressed with respect to the Silo 3 Project to determine applicability. Emphasis was given to the hazards of external and internal exposure to radiation, radioactive contamination, and release of radon gas, because these hazards are a major concern to DOE and the public.

Table A.3.4. Matrix of Tasks/Subtasks vs. Hazards for Silo 3 Facility

HAZARD TYPE	ID Number	STORAGE, S&M	CONSTRUCTION	OPERATION AND MAINTENANCE			DEMOBILIZATION
				Material Retrieval	Process Building Operations	Filled Container Management	
Potential/Kinetic Energy							
Drop crane load	2a		X			X	X
Personnel fall from heights	2b	X	X	X	X		X
Drop tools/equipment	2c	X	X	X	X	X	X
Crane load swing	2d		X			X	X
Structural failure of silo due to degraded condition and excessive load	2e	X	X	X	X	X	X
Vehicle crash into facility	2f	X	X	X	X	X	X
Chemical Energy							
Fire/explosion from fuels	3a		X			X	X
Electrical Energy							
Overhead lines	5a		X				X
Utility connection/disconnection	5b		X				X
Hand tools/maintenance	5c	X	X	X	X	X	X
Human Capability and Hazards							
Inadequate lighting	6a	X	X	X	X	X	X
Slips, trips, and falls	6b	X	X	X	X	X	X
Pinch points	6c	X	X	X	X	X	X
Noise	6d	X	X	X	X	X	X
Heat/cold stress	6e	X	X	X	X	X	X
Human error due to clutter	6f	X	X	X	X	X	X
Human error due to equipment layout, human factors, ergonomics	6g			X	X		
Human error due to remote camera failure	6h			X	X		
Human error due to schedule pressure, communications failure, complicated tasks	6i	X	X	X	X	X	X

Table A.3.4. Matrix of Tasks/Subtasks vs. Hazards for Silo 3 Facility

HAZARD TYPE	ID Number	STORAGE, S&M	CONSTRUCTION	OPERATION AND MAINTENANCE			DEMOBILIZATION
				Material Retrieval	Process Building Operations	Filled Container Management	
Mechanical Energy							
Hand and power tools, rotating/conveying machinery	11a		X	X	X		X
Natural Phenomena							
Lightning, wind, tornado, earthquake	12a	X	X	X	X	X	X
Radiation							
Exposure from Silo 3 material storage	14a	X	X	X	X	X	X
Hose rupture during pneumatic retrieval	14b			X			
Silo wall failure due to wall cutting operations	14c		X	X			
Spill material from conveyor failure	14d			X	X		
Breach of a material storage bag	14e				X	X	
Spill contents of a cargo container	14f					X	
Dust collector failure	14g			X	X		
Silo collapse from pressure differential	14h			X			
Toxicants							
Concrete burns, paints, chemicals, silica, fuel, oil	16a		X	X	X	X	X
Spill of ferrous sulfate	16b				X		
Chemicals-such as lead and beryllium	16c		X	X	X	X	X
Biohazards							
Poison ivy, snakes, bees and insects	17a		X			X	X
Industrial Hazards							
Welding and burning	21a		X				X
Confined space entries	21b		X				X
Traffic-trucks, heavy equipment, people	21c		X			X	X

Note: The final integrated hazard analysis ID numbers designate specific hazards that are addressed in Table A.4.1.

A.4.0 FINAL HAZARD ASSESSMENT TABLE

The hazard selection criteria for the final integrated hazard analysis table have an emphasis on radiological hazards because of the nature of the waste materials. The criteria include:

- worker exposure to physical, chemical, or radiological hazards while performing the identified task or subtask;
- spread of radioactive contamination because of inadequate administrative controls;
- release of toxic or radiological materials to the atmosphere, ground, or groundwater because of catastrophic failure of an SSC;
- health and safety hazards to workers during general construction; and
- standard industrial hygiene and safety hazards in an industrial facility.

The final integrated hazard analysis table, Table A.4.1 is organized as described in Section A.3.1 for each task and subtask. The hazard types are the applicable hazards taken from *Hazard Analysis Report for Operable Unit 4 (OU4)*, Appendix B (Ref. 3).

This information was then used to identify safety hazards that require special attention and/or additional analysis. Table A.3.2 contains the criteria for significant hazards as defined in NS-0003, *Safety Assessment Hazard Screening and Classification* (Ref. 2). Table A.3.3 provides the consequence classifications employed for this final integrated hazard analysis. These consequence classifications were selected for inclusion in the final integrated hazard analysis tables under the heading of "severity."

The frequency and severity of the unmitigated hazard consequence are listed in the final integrated hazard analysis table. If the intersection of the hazard consequence and the hazard frequency falls within the cross-hatched area of Table A.3.2, the hazard is designated as a significant hazard and the column is marked "Yes." If the intersection is outside the cross-hatched area, the hazard is not designated a significant hazard and the column is marked "No." Standard industrial hazards are marked "SIH."

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Table A.4.1. Final Hazard Assessment for the Silo 3 Project

ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
2a	Drop crane load during construction, container handling, or demobilization	Crane lifts	Personnel injury, equipment damage	Y	-	-	SIH	Qualified riggers and equipment operators. Inspect rigging. Uses approved procedures. Appropriate approval for critical lifts. A dropped load over the silo is addressed in ID No. 2e. A spilled container is addressed in ID No. 14f.
2b	Crane load swing	Crane lifts	Personnel injury, equipment or facility damage	Y	-	-	SIH	Qualified riggers and equipment operators. Inspect rigging. Uses approved procedures. Appropriate approval for critical lifts.
2c	Drop tools/ equipment	Working at heights	Personnel injury	Y	-	-	SIH	Hard hats, safety nets or tie off of tools as necessary.
2d	Personnel fall	Working at heights	Personnel injury or fatality	Y	-	-	SIH	Fall protection when working at heights >6 ft, personnel training, PPE, barriers.

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ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
2e	Structural failure of silo due to degraded structural condition	Drop load, excessive load, or earthquake	Release of radioactivity	N	Anticipated	Low	Yes	Based on the uncertainty in the structural integrity, the life expectancy cannot be determined. Therefore, failure is anticipated. Consequence analysis performed in SA-CALC-052.
2f	Vehicle crash into facility	Vehicle traffic in immediate area	Release of radioactivity	N	Anticipated	Very Low	No	Work sequencing, traffic control, and training.
3a	Fire	Fuel storage and use, or ignition source	Damage to equipment and facilities. Personnel burns and injury.	Y	-	-	SIH	Storage in accordance with NFPA. Minimize combustibles. Fire protection program.
5a	Electric shock	Strike overhead power lines with equipment	Electrocution, burns, shock	Y	-	-	SIH	Maintain minimum distance per OSHA.
5b	Electric shock	Install or disconnect electric power	Electrocution, burns, shock	Y	-	-	SIH	Qualified electrical workers, lockout/tagout program, proper tools
5c	Electric shock	Use of hand tools, maintenance	Electrocution, burns, shock, or fatality	Y	-	-	SIH	Qualified electrical workers, lockout/tagout program, proper tools, use ground fault interrupters
6a	Impaired vision	Inadequate lighting	Personnel injury	Y	-	-	SIH	Human factors review of facility design, provide adequate temporary lighting, per OSHA, for construction and D&D.

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ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
6b	Slips and trips	Icy surface, uneven working surface, poor housekeeping	Personnel injury	Y	-	-	SIH	Housekeeping to minimize clutter and ice, sturdy work shoes, design reviews to ensure adequate surfaces.
6c	Pinch points	Material handling	Personnel injury	Y	-	-	SIH	Wear work gloves when appropriate, equipment guards, training.
6d	Noise	Work around heavy equipment, process equipment	Hearing loss	Y	-	-	SIH	Noise monitoring, post areas, use hearing protection, enclose noise source, noise isolation.
6e	Heat or cold stress	Weather, work in PPE	Heat- and cold-stress-related injuries	Y	-	-	SIH	Monitor for heat and cold stress during work activities. Wear proper clothing when possible. Uses breaks and fluids, as needed.
6f	Human error	Work around clutter	Personnel injury	Y	-	-	SIH	Housekeeping
6g	Human operations error	Work with inadequate equipment, valve, or controls layout. Inadequate ergonomics	Personnel injury, equipment damage	Y	-	-	SIH	Human factors review of layout, programming, and ergonomics. Training on hierarchy of process controls.
6h	Human operations error	Remote camera failure	Mishandle material, personnel injury	N	Unlikely	Very low	No	Design of remote camera system, mockup testing, backup visual methods where possible.

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ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
6i	Human error	Schedule pressure, communication failure, complicated tasks	Personnel injury	Y	-	-	SIH	Training, procedures. Appropriate work schedule.
11a	Rotating energy	Use of hand and power tools, motors	Personnel injury	Y	-	-	SIH	Qualified workers, training, guards where possible.
12a	Natural phenomena	High winds, tornadoes, lightning, earthquake	Personnel injury, equipment damage	Y	-	-	SIH	Monitor weather, take cover when weather threatens. Silo failure due to earthquake addressed in ID No. 2e.
14a	External radiation exposure	Work near the Silo 3 material storage areas	Potential to exceed dose limits	N	Anticipated	Very Low	No	TLDs and RWPs as required by 10 CFR 835
14b	Radiation exposure	Hose rupture during pneumatic retrieval	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design, structure over work area.
14c	Radiation exposure	Silo wall cutting operations and subsequent structural collapse	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design, structure over work area.
14d	Radiation exposure	Spill material due to a conveyor failure	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design, structure over work area.
14e	Radiation exposure	Breach of a material storage bag	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design, structure over work area.

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ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
14f	Radiation exposure	Spill contents from a cargo container	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design.
14g	Radiation exposure	Dust collector failure	Potential to exceed dose limits	N	Anticipated	Low	Yes	Approved procedures, training, process and equipment design.
14h	Radiation exposure	Silo pressurization of depressurization and collapse during pneumatic retrieval	Potential to exceed dose limits	N	Depressur-ization Anticipated Pressur-ization Extremely Unlikely	Low	Yes	Approved procedures, operator training, process and equipment design, and structure over silo. Silo pressurization is mitigated by the maximum achievable pressure, which is within failure limits and by the relief valves. Depressurization requires multiple failures and could result in a pressure differential exceeding failure limits.
16a	Exposure to toxic materials	Use of concrete, paints, chemicals, fuel, oil, silica	Skin irritation, respiratory system damage, or other physical effects	Y	-	-	SIH	Use appropriate PPE, MSDS.
16b	Exposure to toxic materials	Spill of ferrous sulfate	Skin irritation, respiratory system damage, or other physical effects	N	Anticipated	Low	Yes	Approved procedures, training, equipment design, use appropriate PPE.

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ID No.	Hazard Type	Initiating Event	Consequence (Unmitigated)	SIH * Yes/No	Frequency	Severity	Significant Hazard	Comments, Mitigators, Controls, Actions, and/or Justification
16c	Exposure to chemicals such as lead and beryllium	Spill or release of Silo 3 material.	Personnel injury	Y			SIH	Use appropriate PPE, approved procedures, equipment design.
17a	Exposure to poison ivy, snake bites, insect stings	Work outdoors	Personnel injury	Y	-	-	SIH	PPE, repellants. Removal of potential hazards (snakes, ivy, etc.)
21a	Exposure to welding operations	Welding and torch cutting	Eye injury, burns, respiratory, fire	Y	-	-	SIH	Training, qualified welders, PPE, fire watch
21b	Confined space	Construction, maintenance, operations, inspections requiring confined space entry	Asphyxiation, injury, or death	Y	-	-	SIH	Training, PPE, ventilation, retrieval and rescue provisions
21c	Traffic	Material delivery, transport, construction, demolition	Personnel injury, equipment damage	Y	-	-	SIH	Observe speed limits; establish/maintain appropriate traffic patterns, traffic control devices, warning equipment, and backup warning devices.

*SIH = standard industrial hazards, Y = yes, N = no
CFR = *Code of Federal Regulations*
D&D = decontamination and decommissioning
MSDS = Material Safety Data Sheets
NFPA = National Fire Protection Association
OSHA = Occupational Safety and Health Administration
PPE = personal protective equipment
RWP = radiological work permit
TLD = thermoluminescent dosimeter

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A.5.0 CONCLUSIONS OF THE FINAL INTEGRATED HAZARD ANALYSIS

The final integrated hazard analysis table was analyzed to identify any significant concerns that require further analysis. Most of the potential hazards were found to be anticipated accidents with very low consequences. However, some potential hazards were found to be significant and are discussed in the following sections.

A.5.1 ANALYSIS OF FINAL INTEGRATED HAZARD ANALYSIS TABLE

The methodology described in Section A.3.0 and represented in Table A.3.1 was used to assess the hazards in Table A.4.1. All the potential hazards were anticipated or unlikely accidents with very low consequences. The following exceptions are significant hazards that require further analysis:

- Structural failure of silo due to a dropped load, excessive load, or earthquake
- Hose rupture during pneumatic retrieval
- Silo wall failure due to wall cutting operations
- Spill material due to a conveyor failure
- Breach of a material storage bag
- Dust collector failure
- Silo depressurization and collapse
- Spill of ferrous sulfate
- Spill contents from a cargo container

The frequency and severity of the standard industrial hazards are not specified in Table A.4.1, which is consistent with the *Hazard Analysis Report for Operable Unit 4 (OU4)*, Appendix B Ref. 3. However, some standard industrial hazards with unlikely frequency may have significant consequences and these hazards warrant some additional consideration. Electrical energy, confined space, and potential energy or elevation hazards have an unlikely frequency and moderately severe consequences, including the possibility of death. The consequence of contact with electrical sources may be a fatal electrocution. The consequence of working in a confined space may be a fatal asphyxiation. The consequence of working at elevated heights may be a fatal fall.

A.5.2 RESOLUTION OF CONCERNS

The need for a comprehensive health and safety program for the Silo 3 Project is clearly recognized. Health and safety specialists were assigned to review the design process and evaluate the potential hazards. The health and safety specialists worked directly with the designers and were active participants in design review meetings and formal design review processes. Jacobs is committed to a rigorous environmental, health, and safety program for the Silo 3 Project. A strong, comprehensive health and safety program minimizes the frequency of accidents.

The hazard of working with energized electrical power sources is rigorously controlled at FCP by energy isolation plans, service interruption permits, and formal lock-out/tag-out procedures (Refs. 19 and 20). Entry into confined spaces is rigorously controlled by formal evaluations by FCP industrial hygiene staff and confined space entry permits (Ref. 21). Working at elevated heights (higher than 6 ft) is rigorously controlled by the FCP fall protection program, which requires harnesses, lanyards, and anchor points in accordance with Occupational Safety and Health Administration standards (Ref. 22).

Potential accidents with significant consequences are concerns that were continuously addressed throughout the design cycle. The results of the final integrated hazard analysis were used in selecting the particular accident scenarios analyzed, which allows the determination of any safety SSCs.

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