00-0000137

Department of Energy
Savannah River Operations Office
P.O. Box A
Aiken, South Carolina 29802

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DNF SAFETY BOARD

FEB 09 2000

The Honorable John T. Conway, Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW
Suite 700
Washington, DC 20004-2901

Dear Mr. Conway:

On September 13, 1999, I appointed a Type B Accident Investigation Board to investigate the intakes of plutonium that occurred at the FB-Line facility on September 1, 1999.

The investigation and report were completed in accordance with DOE Order 225.1A, "Accident Investigations." A copy of the report is enclosed for your use. I have also provided copies to your site representatives. We would be pleased to brief the Safety Board on the results of the investigation, either in your Washington, DC office or via a videoconference at your convenience.

Any questions may be directed to me or Jeff Allison, Accident Investigation Board Chairman, at 803-725-0365.

Sincerely,

Greg Rudy
Manager

VA-00-0020

Enclosure:
Type B Accident Investigation
Report

cc w/o encl:
M. B. Whitaker (EH-9), HQ
C. A. Huntoon (EM-1), HQ

Final Report **February 2000**

Type B Accident Investigation Board Report of the September 1, 1999, Plutonium Intakes at the Savannah River Site FB-Line

Savannah River Operations Office

Type B Accident Investigation Report of the September 1, 1999, Plutonium Intakes at the Savannah River Site FB-Line

On September 13, 1999, I established a Type B Accident Investigation Board to investigate plutonium intakes by personnel on September 1, 1999, at the Savannah River Site FB-Line.

The Board's responsibilities have been completed with respect to this accident. The analysis, identification of direct, contributing, and root causes, and judgments of need reached during the investigation were performed in accordance with DOE Order 225.1A, *Accident Investigations.* I accept the findings of the Board and authorize the release of this report for general distribution.

Greg Rudy, Manager
Savannah River Operations Office

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ACRONYMS AND GLOSSARY OF TERMS

ACRONYMS

ALARA	As Low As Reasonably Achievable
AMMFS	Assistant Manager for Material and Facility Stabilization
AOP	Abnormal Operating Procedure
ARA	Airborne Radioactivity Area
CA	Contamination Area
CAM	Continuous Air Monitor
CEDE	Committed Effective Dose Equivalent
CND	Criticality Neutron Dosimeter
DOE	Department of Energy
dpm	disintegrations per minute
EOP	Emergency Operating Procedure
HCA	High Contamination Area
HRA	High Radiation Area
HVAM	High Volume Air Monitor
ISMS	Integrated Safety Management System
JHA	Job Hazards Analysis
MC&A	Material Control and Accountability
NIST	National Institute of Standards and Technology
OPS	Operations personnel
Pu	Plutonium
rem	Roentgen equivalent man
RWP	Radiological Work Permit
RCO	Radiological Control Operations/Inspector
SOP	Standard Operating Procedure
SR	Savannah River Operations Office
S/RID	Standards/Requirements Identification Document
SRS	Savannah River Site
SRTC	Savannah River Technology Center
TLND	Thermoluminescent neutron dosimeter
WSI-SRS	Wackenhut Services Incorporated-Savannah River Site
WSRC	Westinghouse Savannah River Company

GLOSSARY OF TERMS

Airborne Radioactivity Area. Any area where the concentration of airborne radioactivity above natural background levels exceeds or is likely to exceed 10 percent of derived air concentration values. For certain radionuclides, derived air concentration is the airborne concentration equaling the annual limit on intake divided by the volume of air breathed by an average worker for a working year of 2000 hours, assuming a breathing volume of 2400 cubic meters per year.

Bagless Transfer System. Canning equipment for removing plutonium from a glovebox and placing it into a welded, contamination-free storage container.

Bioassay. A determination of the kinds, quantities, or concentrations (and, in some cases, locations) of radioactive material in the human body by direct measurement or by analysis, and evaluation of radioactive materials excreted or removed from the human body.

Contamination Area. Any area where removable contamination levels are greater than the values specified in Appendix D of 10 CFR 835, *Occupational Radiation Protection*, but do not exceed 100 times those values.

Committed Effective Dose Equivalent. The sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor. A committed dose equivalent is the dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body.

Disintegrations per minute. The rate of transformation by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for the background count rate, detector, efficiency, and geometric factors associated with the instrumentation.

High Radiation Area. Any area accessible to individuals in which radiation levels could result in an individual receiving a deep dose equivalent in excess of 0.1 rem in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Monitoring. The measurement of radiation levels, airborne radioactivity concentrations, radioactive contamination levels, quantities of radioactive material, or individual doses and the use of the results to evaluate radiological hazards or potential and actual doses resulting from exposures to ionizing radiation.

Radiological Buffer Area. An area established to prevent the spread of contamination, protect personnel from radiation exposure, and provide a buffer area between controlled areas and radiological areas.

Radiological Work Permit. A permit that identifies radiological conditions, establishes worker protection and monitoring requirements, and contains specific approvals for radiological work activities.

Roentgen equivalent man. Unit of dose equivalent.

PROLOGUE

The September 1, 1999, accident at the Savannah River Site's FB-Line facility occurred when plutonium was released from a failed bagless transfer can, resulting in plutonium intakes by at least seven workers (additional workers are being evaluated). The bagless transfer can was considered by contractor management to be an integral component in the overall safety strategy for the FB-Line. Despite this reliance on the canister's integrity, adequate quality assurance controls were not in place to ensure that a can with a failed weld would not be stored in the FB-Line vault.

Two root causes were identified for this accident: Quality assurance on the bagless transfer system canister was not adequate to identify the weld defect, and implementation of integrated safety management for plutonium vault operations was inadequate to provide worker protection during interim plutonium storage and handling.

Once the containment system (the bagless transfer can) failed, the physical environment of the vault storage location and adjacent vestibule contributed to the accident. Near stagnant ventilation made operation of the High Volume Air Monitor less than optimum. Command and Control and communication following the accident were not adequate, and contributed to confusion over material control and accountability requirements and delays in alarm response.

This accident highlights the importance of ensuring an effective Integrated Safety Management System approach to operations. Several of the conclusions reached by the Accident Investigation Board are similar to conclusions reached during the 1997 Type B accident investigation of the plutonium intake by a crane operator at the Savannah River Site's F-Canyon. Specifically, parallels can be drawn in the areas of casualty response to radiological events and procedure compliance for routine or low hazard work. FB-Line had made progress in establishing an Integrated Safety Management System, including completion of a Phase II integrated safety management review in 1997. However, during this accident investigation, deficiencies were identified in each of the five core functions of integrated safety management. There is a need for the contractor and the Department of Energy Savannah River Operations Office to analyze FB-Line operations and take appropriate corrective action to ensure feedback and improvement aspects of integrated safety management are effectively implemented.

EXECUTIVE SUMMARY

INTRODUCTION

On September 1, 1999, at least seven personnel working in an area inside the Department of Energy (DOE) Savannah River Site (SRS) FB-Line facility received intakes of plutonium (additional workers are being evaluated). The plutonium intakes were determined through analysis of chest counting data and screening of bioassay samples provided by the subject individuals. Estimated doses were initially provided for four of the individuals on September 9, 1999. One individual's estimated dose exceeded 10 rem total effective dose equivalent but was less than 25 rem, meeting the criteria for a Type B accident investigation as defined in DOE Order 225.1A, *Accident Investigations*. The DOE Savannah River Operations Office (SR) categorized the accident on September 10, 1999, in accordance with DOE Order 225.1A. On September 13, 1999, the SR Manager formed a Type B Accident Investigation Board (Board).

In conducting its investigation, the Board used various analysis techniques, including events and causal factors charting and analysis, barrier analysis, change analysis, and root cause analysis. The Board walked down the accident site and relevant facility features, reviewed events surrounding the accident and recovery actions, conducted extensive interviews and document reviews, and performed analyses to determine the causal factors that contributed to the accident, including management system deficiencies. Relevant management systems and factors that could have contributed to the accident were evaluated using the core functions of DOE's Integrated Safety Management System, as described in DOE P 450.4, *Safety Management System Policy*.

ACCIDENT DESCRIPTION

On September 1, 1999, FB-Line reported an occurrence involving personnel contamination with positive nasal/saliva smears (SR-WSRC-FBLINE-1999-0026). The FB-Line facility was performing routine vault operations when the high volume air monitor (HVAM) alarmed. Personnel involved suspended operations, secured the vault and exited the area. The HVAM planchet collecting an air sample from inside the vault read 80,000 disintegrations per minute (dpm) alpha. Radiological Control Operations personnel surveyed the retrospective air sample filter paper in the vault/vestibule area and it read 80,000 dpm alpha. A subsequent survey of the filter paper, conducted after exiting the vestibule area, indicated 140,000 dpm alpha. After personnel exited the Contamination Area and monitored on the personal contamination monitor model 1B, two persons received an alarm during monitoring. Alarm Response Procedures and Abnormal Operating Procedures were initiated. All personnel involved in the vault operations were subsequently escorted to the F-Canyon Decontamination Facility located in building 221-F. Nasal and saliva smears were obtained from all affected individuals. Smears were positive for six of the individuals involved in the vault activities. Personnel were moved to medical facilities in buildings 704-F and 719-H for further evaluation and processing. The FB-Line facility established the affected areas of the facility as Contamination Areas and confirmed that the boundaries to the areas were intact.

CAUSAL FACTORS

Causal factors are the events and conditions that produced or contributed to the accident. The direct cause is defined as the immediate event or condition causing the accident. The Board determined the direct cause of the accident was the release of plutonium from a defective bagless transfer can, resulting in inhalation of plutonium by FB-Line workers.

Root causes are factors that, if corrected, would prevent recurrence of the same or similar accidents. The Board identified two root causes of the September 1 accident:

- Quality assurance on the bagless transfer system canister was not adequate to identify the weld defect.
- Implementation of integrated safety management for plutonium vault operations was inadequate to provide worker protection during interim plutonium storage and handling.

Contributing causes are defined as events or conditions that collectively with other causes increased the likelihood of an accident, but individually did not cause it. The Board identified as contributing causes less than adequate performance in the following areas: verbatim compliance with procedures, vault/vestibule ventilation, vault HVAM alarm response, radiological work practices, Material Control and Accountability response under abnormal conditions, security post orders, pre-job briefs, Command and Control, and vault HVAM operation.

The following management issues were identified during the investigation but were determined not to be causal factors:

- Lack of established SRS standards for vault and vestibule airflow.
- Lack of established SRS standards for minimum airflow to optimize HVAM performance.
- Weakness in personnel survey techniques and capabilities for detection of alpha contamination.
- Weakness in utilization of personnel decontamination facilities.

CONCLUSIONS AND JUDGMENTS OF NEED

Table ES-1 presents the Board's conclusions and judgments of need. The Board's conclusions are based on facts and pertinent analytical results. From the conclusions, the Board developed judgments of need to guide managers in developing follow-up actions. Follow-up actions should include physical, managerial, administrative and safety management system controls and practices necessary to resolve the conditions identified in the conclusions for each judgment of need.

Table ES-1. Conclusions and Judgments of Need

Conclusions	Judgments of Need
The bagless can was not subject to an adequate quality assurance program during production commensurate with its role as a primary barrier protecting the workers. Areas requiring particular emphasis include the visual inspection and the leak checks (gross and helium), both of which failed to detect the hole in the bagless can weld.	Westinghouse Savannah River Company (WSRC) needs to define appropriate quality assurance controls for the bagless can, develop remedial measures for cans already produced, and evaluate whether remedial measures are necessary for all other types of containers in the vault. WSRC needs to provide qualified weld inspectors with appropriate training and equipment to enable an independent inspection of weld quality for bagless transfer system cans. WSRC needs to evaluate the operation, maintenance, and calibration of the leak detection system to ensure satisfactory weld failure detection.

Conclusions	Judgments of Need
WSRC management expectations regarding following procedures and work standards were not enforced for conduct of operations. For example, instances of non-compliance with operating procedures and Radiological Work Permits (RWP) occurred prior to and during the accident. Additionally, communications between workers during the event did not permit affected personnel to understand the nature of the event, and communications between affected workers and supervision did not result in adequate supervisory direction during the event. Pre-Job Briefings did not include comprehensive coverage of radiological contingencies.	WSRC management needs to communicate and enforce expectations regarding conduct of operations. WSRC needs to evaluate the required content of pre-job briefings and ensure that required topics are appropriately covered.
WSRC management expectations regarding following procedures and work standards were not enforced for radiological controls. For example, there was failure to perform an RWP-required survey of items prior to handling, failure to completely characterize work site radiological conditions, failure to completely survey failed can prior to initiation of decontamination, failure to terminate work when the RWP suspension guide limit was reached, failure to utilize radiological boundaries at the Contamination Area/Airborne Radioactivity Area to Contamination Area transition, and failure to survey personnel exiting the vault following receipt of the HVAM alarm.	WSRC management needs to communicate and enforce expectations regarding conduct of radiological operations.
Command and Control during the material handling evolution and response to the HVAM alarm was inadequate.	WSRC management needs to ensure command and control concepts are understood and implemented by supervisory personnel.
The facility drill program did not include day crew operations and security group personnel likely to be affected by an actual event.	WSRC management needs to improve the facility drill program by including all organizations that could be impacted by actual facility events.

Conclusions	Judgments of Need
Issues identified for this accident are similar to those identified in the 1997 DOE Type B Accident Investigation report of a plutonium intake by a crane operator at the SRS F-Canyon. Similarities include failure to adequately characterize work site radiological conditions, inadequate job planning/work package preparation/pre-job briefs/ALARA reviews, failure to ensure verbatim compliance with procedures, inadequate specification of who was responsible for the job, failure to perform adequate Job Hazard Analyses, and inadequate management analysis of operating conditions.	WSRC management and DOE-SR line management need to (a) analyze the adequacy of F-Canyon lessons learned implementation and develop corrective actions, (b) validate any corrective actions already implemented by FB-Line as a result of the F-Canyon accident, and (c) determine why corrective actions taken in response to the F-Canyon accident investigation report were not effective in mitigating the effects of this accident.
Due to lack of facility guidance, operations staff were unclear of Material Control and Accountability requirements during an abnormal event.	WSRC needs to include Material Control and Accountability requirements during abnormal conditions in facility procedures and train affected personnel.
WSRC and Wackenhut Services Incorporated-Savannah River Site (WSI-SRS) lack adequate interface during abnormal conditions.	WSRC and WSI-SRS need to develop a plan for improving communications and coordination between operations, Radiological Control Operations, and WSI-SRS during abnormal conditions.
Security post orders did not contain response requirements for abnormal conditions.	WSI-SRS needs to ensure security post orders contain response requirements for abnormal conditions.
WSRC and DOE-SR have been presented with many opportunities in the past to rectify problems identified either by them or others that resurfaced in this investigation and contributed to the accident.	WSRC and DOE-SR senior management need to determine the root causes of ineffectiveness in their feedback and improvement mechanisms and develop appropriate corrective action.
WSRC management did not adequately implement integrated safety management for plutonium vault operations.	WSRC senior management, independent of line management, needs to analyze why the breakdown in integrated safety management implementation for plutonium storage and handling activities occurred, and develop appropriate corrective actions. WSRC management needs to (a) analyze FB-Line vault/vestibule operations for worker protection and define appropriate controls, and (b) review other analyses for worker protection within FB-Line for adequacy and correct any identified deficiencies.
DOE-SR did not develop a site-specific technical basis document for interim storage of plutonium-bearing materials.	DOE-SR needs to develop a site-specific technical basis document for interim storage of plutonium-bearing materials.

1.0 INTRODUCTION

1.1 BACKGROUND

On September 1, 1999, at least seven personnel working in an area inside the Department of Energy (DOE) Savannah River Site (SRS) FB-Line facility received intakes of plutonium (additional workers are being evaluated). The plutonium intakes were determined through analysis of chest counting data and screening of bioassay samples provided by the subject individuals. Estimated doses were initially provided for four of the individuals on September 9, 1999. One individual's estimated dose exceeded the 10 rem total effective dose equivalent threshold but was less than 25 rem, meeting the criteria for a Type B accident investigation as defined in Department of Energy (DOE) Order 225.1A, *Accident Investigations*, Attachment 2, paragraph 2b(4)(a). The DOE Savannah River Operations Office (SR) categorized the accident on September 10, 1999, in accordance with DOE Order 225.1A. On September 13, 1999, the SR Manager formed a Type B Accident Investigation Board (Board).

1.2 FACILITY DESCRIPTION

SRS is a large government-owned industrial complex covering more than 300 square miles in South Carolina. Under contract with DOE, Westinghouse Savannah River Company (WSRC) is responsible for integrating and managing the safe and effective operation and maintenance of site facilities. Wackenhut Services Incorporated-Savannah River Site (WSI-SRS) is a paramilitary organization contracted by DOE to provide total security support services for SRS, including access control, property protection, alarm equipment monitoring, and Special Response Teams.

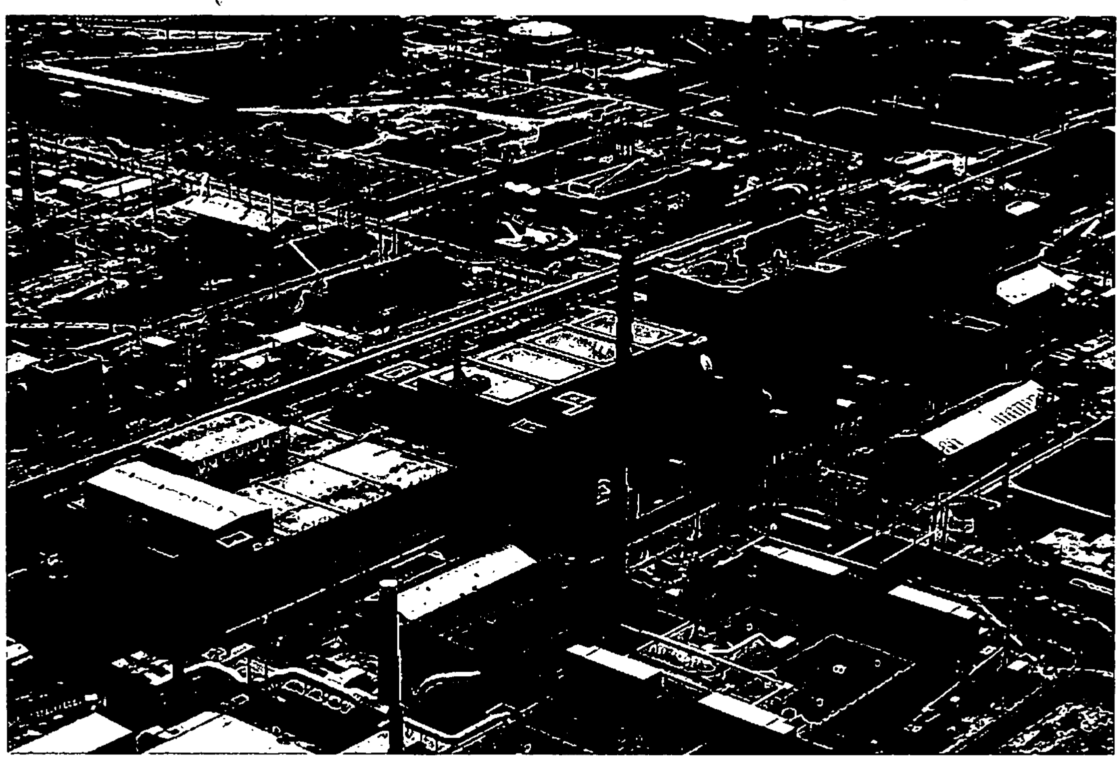


Figure 1-1 F-Canyon Overview

FB-Line is located in F-Canyon Building 221-F *(see Figure 1-1)*, specifically in Sections 1 through 5 on the third through sixth levels, plus the south loading dock on the second level of Section 1 (see *Figure 1-2*). In the past, FB-Line was used to convert plutonium nitrate, recovered from spent fuel and targets in the 221-F Canyon, to plutonium metal. FB-Line's current mission is to process existing inventories of plutonium and plutonium-bearing materials to achieve a suitable form for long-term storage. The processing equipment is contained in process enclosures (cabinets or gloveboxes) to prevent contamination of operating areas, and is confined to the fifth and sixth levels. In addition to processing activities, waste handling operations take place throughout the facility, and miscellaneous plutonium vault storage operations take place in two vaults located on the third and fourth levels.

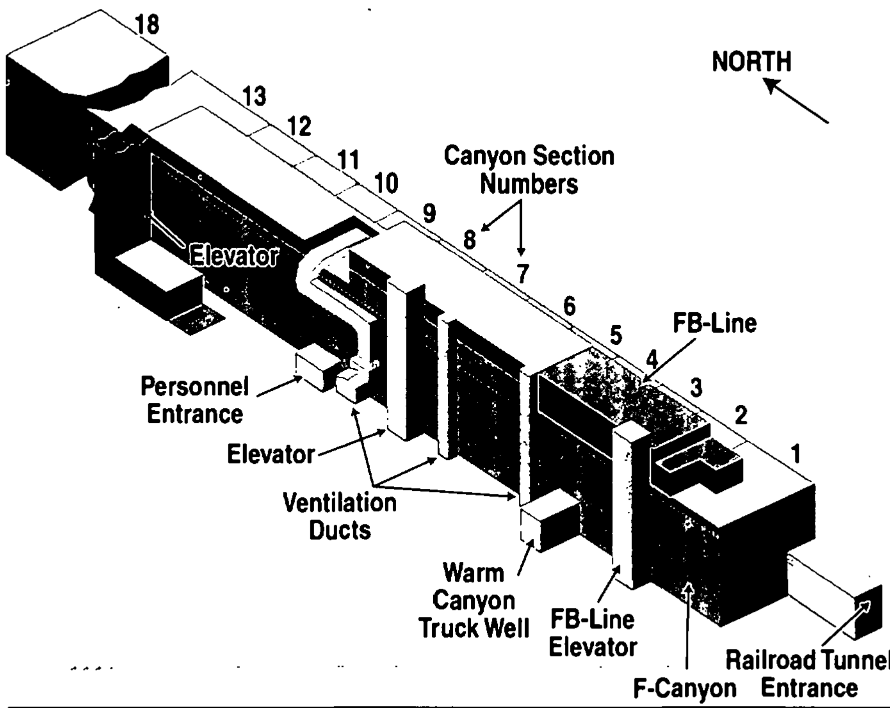


Figure 1-2 F-Canyon Isometric Drawing

FB-Line Bagless Transfer System

The end of the Cold War led to a re-evaluation of plutonium storage throughout the DOE Complex. Existing storage container and vault configurations for in-process plutonium were not adequate for long-term storage of up to 50 years. Revised designs envisioned plutonium being sealed in a set of robust, contamination-free, welded stainless steel containers. The design required that plutonium be placed in storage containers without including the plastic bag normally used when materials were removed from a cabinet or glovebox using a plastic heat-seal technique. Plastic had been shown to degrade in contact with plutonium, creating pyrophoric products with plutonium metal and generating gaseous products with plutonium oxide. The Savannah River Technology Center (SRTC) developed a bagless transfer system meeting inner container design specifications in accordance with a 50-year plutonium storage standard (DOE-STD-3013-94, *Criteria for Preparing and Packaging Plutonium Metals and Oxides for Long-Term Storage*). In 1997, a bagless transfer system was designed and installed in FB-Line for packaging plutonium metal.

The goal of the bagless transfer system is to remove plutonium metal from a glovebox and seal it in a welded stainless steel can without contaminating the outside of the can. The bagless transfer process takes place in five steps (*Figure 1-3*). The first step is to insert a new canister into the bottom of the glovebox, displacing the remaining portion of the previous canister from the sphincter seal. The seal allows movement of the round canister into the glovebox while preventing leakage of plutonium contamination from the glovebox. The second step is to place

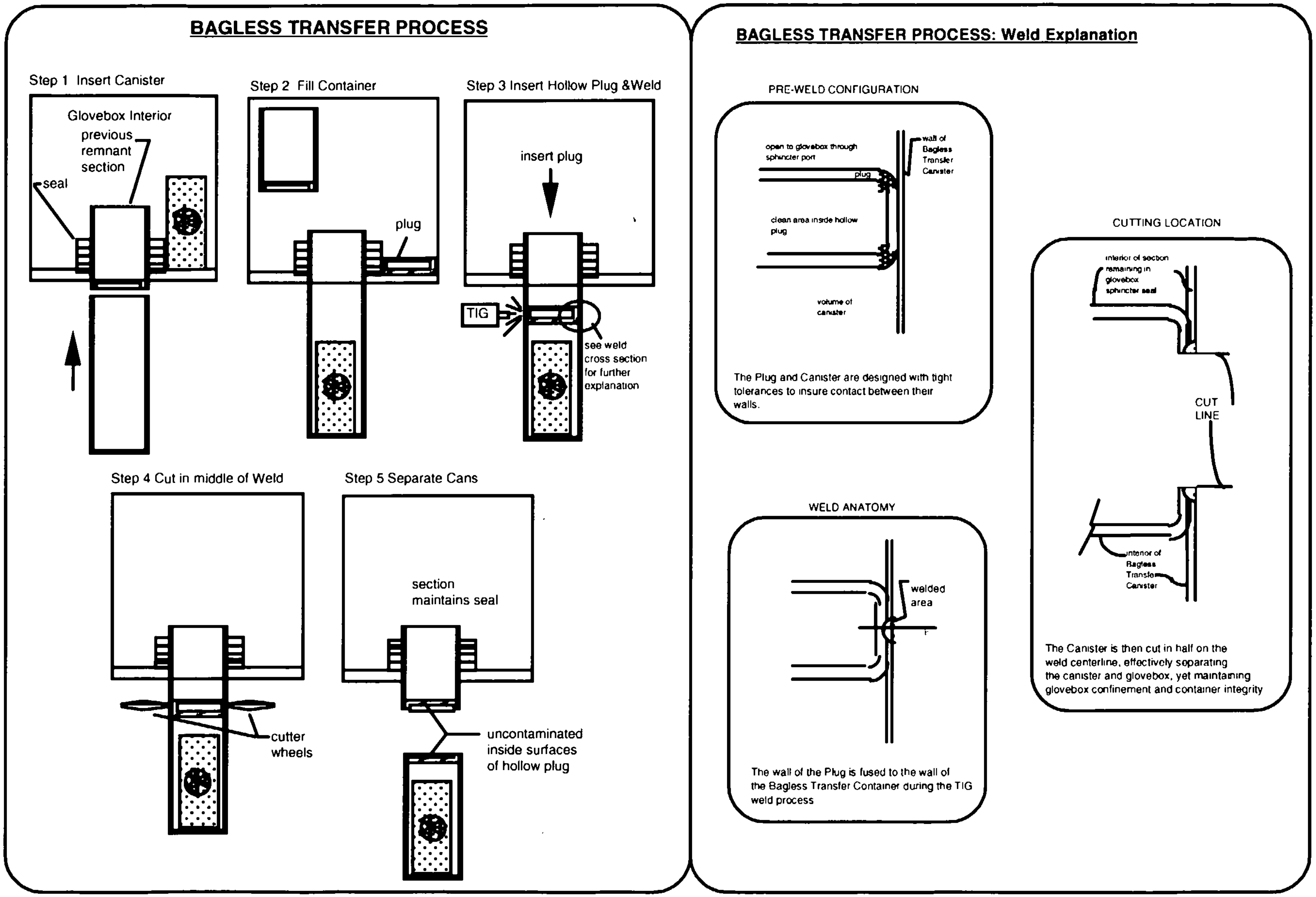


Figure 1-3 Bagless Transfer System Overview

the plutonium into the canister while minimizing contamination of the canister wall, and backfill the canister with helium. The third step is to insert a close-fitting, hollow plug into the container and fuse the outer container to the inner plug via a single-pass, fillerless Gas Tungsten Arc Weld/Tungsten Inert Gas (TIG) welding process. The TIG welder produces three tack welds, about 90 degrees apart, and then begins a continuous overpass weld that completely encircles the can and tapers off after overlapping the start location by a small amount. The fourth step is to cut the container in the approximate center of the weld using a roller-wheel-type pipe cutter. The final step involves leaving the upper portion of the canister in the sphincter seal to maintain glovebox integrity, with the bottom portion becoming a leak-tight, all-metal, welded container.

Weld Integrity Check Equipment

Welding processes are dependent on many parameters that are sometimes difficult to control. Weld defects occur even with the most automated welding machines, and detection of weld defects is an integral part of the welding process. Two leak detection processes were selected to evaluate the quality of welds on the bagless transfer system cans: the Volumetric Leak Test System and the Helium Mass Spectrometer Leak Detection system.

A model 947 Multitest leak detection system was procured from Varian Vacuum Products, Lexington, Massachusetts. This unit allows two separate methods of leak detection. The volumetric gross leak test measures the volume of gas in a bell jar containing the can being evaluated. This test is conducted by evacuating a small vessel, isolating it from the vacuum pump, and connecting it to a bell jar containing the can to be tested. The equilibrium pressure is measured against the pressure expected from a non-leaking can. Any variance indicates a leaking weld. The test unit is calibrated by testing a can known to have no leaks against a similar can with a drilled hole to simulate a weld leak.

The second system is the Helium Leak Detection System. This system is capable of detecting a leak as small as 1×10^{-11} standard cubic centimeters per second using a mass spectrometer specific for helium. To conduct this test, a bagless transfer system can is placed in a vacuum bell jar and the system is evacuated by a high-vacuum turbo pump and two mechanical vacuum pumps. The bell-jar gas content is pulled past a spectrometer tube to detect trace quantities of helium. Helium presence in the gas pumped from the system is measured at three levels of evacuation to allow an estimate of the size of the leak being measured. This test requires helium to be present in the can. A gross leak would have vented the bagless transfer can's helium during the Volumetric Gross Leak Test, so no helium would be available for detection. Therefore, the combination of the two test systems is needed to detect the full range of leaks.

FB-Line Integrated Safety Management System

In August 1997, DOE-SR conducted a Phase I Integrated Safety Management System (ISMS) Verification Review. DOE-SR found that WSRC had submitted an ISMS description, enabling documents, and processes conforming to guidance provided by the DOE-SR Manager, and had implemented ISM from the corporate level through the division to the facility manager level. In October 1997, a Phase II ISMS Verification Review was conducted to determine whether the FB-Line Facility Manager had instituted a system consistent with DOE's policy as interpreted by WSRC in their approved ISMS description. The Phase II review team found that FB-Line management had a safety management system in place. Although opportunities for improvement were identified, no significant issues were raised that had not been previously identified during the Phase I review, routine WSRC Facility Evaluation Board reviews, or through the readiness review process. The issues identified did not result in lack of safety, but contributed to inefficiency and excessive reliance upon Senior Facility Line Management to ensure that work was performed safely. In July 1998, a WSRC Facility Evaluation Board review also assessed FB-Line's ISMS implementation. The Facility Evaluation Board concluded that although

FB-Line had made major improvements since the October 1997 Phase II Verification, some ISMS elements had not been fully implemented. Areas in need of improvement included integration of facility activities, Job Hazard Analysis program implementation, adequacy of procedures and technical reviews, closure of safety audit deficiencies, and integration of division and facility self-assessment programs and the root cause/corrective action portion of the self-assessment program.

1.3 INVESTIGATION SCOPE, CONDUCT AND METHODOLOGY

The Board commenced investigation activities on September 15, 1999. The scope of the Board's investigation included (but was not limited to) identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the accident; developing conclusions; and determining the judgments of need which, when implemented, should prevent recurrence of the accident. In conducting the investigation, the Board completed over 50 recorded interviews, inspected facilities and equipment, reviewed applicable documentation, and evaluated overall management systems. The investigation was performed in accordance with DOE Order 225.1A, *Accident Investigations*; SR Implementing Procedure (SRIP) 200, Chapter 225.1, Rev. 1, *Accident Investigations*; DOE Guide 225.1A-1, Rev. 1 Chg. 1, *Implementation Guide for DOE Order 225.1A, Accident Investigations*; and DOE's May 1999 Workbook, *Conducting Accident Investigations*, Revision 2.

2.0 FACTS AND ANALYSIS

2.1 ACCIDENT DESCRIPTION AND CHRONOLOGY

2.1.1 Background and Accident Description

On September 1, 1999, an Unusual Occurrence (SR-WSRC-FBLINE-1999-0026) was declared, identifying personnel contamination with positive nasal/saliva smears. The FB-Line facility was performing routine vault operations when the high volume air monitor (HVAM) alarmed. Personnel involved suspended operations, secured the vault and exited the area. The HVAM planchet collecting an air sample from inside the vault read 80,000 disintegrations per minute (dpm) alpha. Radiological Control Operations (RCO) personnel surveyed the retrospective air sample filter paper in the vault vestibule area and it read 80,000 dpm alpha. A subsequent survey of the filter paper, conducted after exiting the vestibule area, indicated 140,000 dpm alpha. After personnel exited the Contamination Area (CA) and monitored on the personal contamination monitor model 1B (PCM-1B), two persons received an alarm during monitoring. Alarm Response Procedures and Abnormal Operating Procedures were initiated by FB-Line. All personnel involved in the vault operations were subsequently escorted to the F-Canyon Decontamination Facility located in building 221-F. Nasal and saliva smears were obtained from all affected individuals. Smears were positive for six of the individuals involved in the vault activities. Personnel were moved to medical facilities in buildings 704-F and 719-H for further evaluation and processing. The FB-Line facility established the affected areas of the facility as CAs and confirmed that the boundaries to the CAs were intact.

2.1.2 Chronology of Events

At 0942 hours on September 1, 1999, eight personnel entered the FB-Line vault stairway to perform two tasks: batching and transporting characterization samples per Standard Operating Procedure (SOP) 221-FB-1781-NS, and packaging bagless cans containing plutonium-bearing materials into shipping containers per SOP 221-FB-1186-H-NS. The workers included six FB-Line operations personnel and two RCO inspectors. (To trace and identify activities in this report, these individuals are designated as OPS 1, OPS 2, OPS 3, OPS 4, OPS 5, OPS 6, RCO 1, and RCO 2.) At 0944 hours, OPS 6 remained stationed in the vault stairway and the remaining seven personnel entered the vault/vestibule area (*Figure 2-1*).

In accordance with applicable RWPs, protective clothing and dosimetry requirements were as follows: For routine entry into CAs (including the vestibule) for hands-off work, RWP 99-FBL-007, Rev. 1, required personnel to don a laboratory coat, one pair of plastic shoe covers, one pair of gloves, one pair of glove liners, thermoluminescent neutron dosimeter (TLND), criticality neutron dosimeter (CND), with no respiratory protection required. For hands-on work in the vault/vestibule, RWP 99-FBL-216 required personnel to don a full set of personnel protective equipment for work in the vestibule: one pair of cotton coveralls, two pairs of gloves, one pair of glove liners, one pair of booties, one pair of plastic shoe covers, TLND, CND, an electronic pocket dosimeter, and extremity dosimetry. For work inside the vault, RWP-99-FBL-216 required a minimum of one set of cotton coveralls, two pairs of gloves, one pair of glove liners, one pair of booties, two pairs of plastic shoe covers, one hood, TLND, CND, an electronic pocket dosimeter, supplemental head, chest, and two thigh TLNDs, extremity dosimetry, and a full-face respirator.

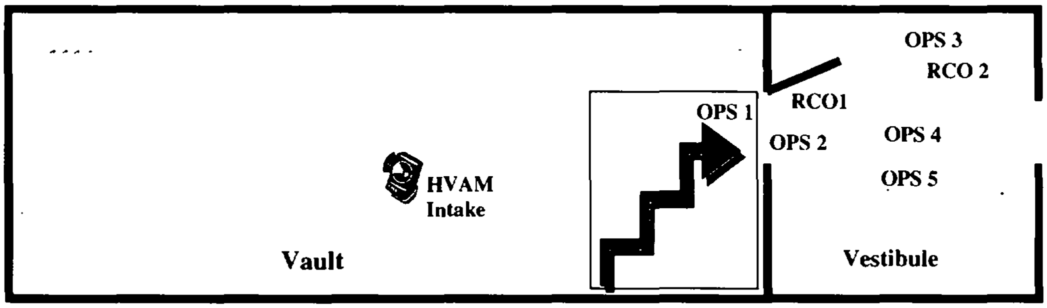


Figure 2-1 Diagram of Vault/Vestibule Area

Upon entering the vault/vestibule area, RCO 2 replaced the vault HVAM planchet and the vestibule air sampler filter paper from the previous day. The sample media were pulled and surveyed, and airborne contamination levels were below the suspension guidelines identified in Radiological Work Permit (RWP) 99-FBL-216. At 0949 hours, operations personnel opened the vault door. RCO 1 entered the vault wearing a full set of protective clothing and respiratory protection (i.e., wearing a full-face respirator). RCO 1 entered the vault to perform general area dose rate surveys and contamination surveys of the vault floor to ensure conditions were within those specified by RWP 99-FBL-216. RCO 1 concluded that radiological conditions were suitable for performing the desired work, and exited the vault, removing respirator, cloth hood and the outer pair of gloves and plastic shoe covers. OPS 1, wearing a full set of protective clothing and a full-face respirator, entered the vault to perform the batching and transporting characterization samples work. Material characterization sample work was completed and the samples were sent to the 772-1F Analytical Laboratory for characterization. Preparations were then made to begin packaging the bagless cans. OPS 1 successfully transitioned four bagless cans into the vestibule for packaging in accordance with SOP 221-FB-1186-H-NS. OPS 1 then brought the fifth can to just outside the vault and placed it on a masselin cloth just inside the vestibule. RCO 1 surveyed the can and detected 2000 dpm alpha/100 cm^2 on the can. RCO 1 instructed OPS 1 to take the can back inside the vault and decontaminate the can to lower levels (the RWP required containers to be <200 dpm alpha/100 cm^2).

Immediately after OPS 1 started decontamination work just inside the vault door (at approximately 1047 hours), the vault HVAM alarm activated both audibly and visually, and also alarmed at the Precipitator Control Room and the HVAM room on the fifth level. The HVAM intake is located approximately in the middle of the vault, with the detector box located in the vestibule area. When the HVAM alarm sounded, OPS 1 placed the bagless can back in its storage position in the vault, but did not secure the can. Between 1048 and 1054 hours, RCO 2 made several phone calls from the vestibule to the HVAM monitoring room located on the fifth level. During these calls, RCO 2 and the RCO responder in the HVAM room discussed whether the alarm could be false (i.e., due to an electrical spike). RCO 2 pulled the planchet from the HVAM and surveyed it, reading 80,000 dpm alpha. At this time, RCO 1 and RCO 2 were responding to the alarm by performing contamination surveys to identify any potential contamination inside the vestibule. Concurrent with the RCO actions, a discussion took place between OPS 1, who had been in the vault and was still wearing his respirator, and OPS 3, who was controlling the work procedure, about the need to secure the bagless can in the vault. At 1053 hours, the operators received a call from their First Line Supervisor and discussed what they should do. The First Line Supervisor called the Operations Command Center to report to the Shift Operations Manager, including a discussion of the vault status. OPS 1 and 3 made the decision to send OPS 1, who was still wearing his respirator, back into the vault to secure the bagless can. OPS 1 entered the vault and secured the bagless can in its location on the west side of the vault. OPS 1 then exited the vault, and was seen by RCO 1 as OPS 1 was closing the vault door. At 1100 hours, a phone call occurred between the First Line Supervisor and OPS 3. OPS 3 informed the First Line Supervisor that the bagless can had been secured in the vault. The vault door was secured at 1104 hours. RCO 1 surveyed the air filter sample paper on the vestibule air sampler, and it read 80,000 dpm alpha. The filter paper was replaced and brought out of the vestibule area. A subsequent survey of the filter paper, conducted after exiting the area, indicated 140,000 dpm alpha.

RCO 1 informed the group that they needed to exit the vestibule area and proceed down the stairway to perform a whole body frisk. At approximately 1105 hours, the group of seven left the vestibule together, in close proximity to one another. OPS 6 performed a trans-frisk and followed the group of seven out of the stairway to the third level. At approximately 1116 hours, the eight individuals completed doffing protective clothing at the exit from the CA, re-entered the facility through a door, and monitored on a count rate meter equipped with an alpha contamination detector. None of the individuals alarmed the count rate meter (set to alarm at 100 counts per minute above background, which is typically zero for an alpha instrument). The group was then instructed by RCO 1 to perform a whole body survey utilizing a PCM-1B. The PCM-1B on the third level was out of service, so the group proceeded to the fifth level PCM-1B, where six of eight cleared the PCM-1B. Five of the six (OPS 2, OPS 3, OPS 4, RCO 1, and RCO 2) reported to the third-level RCO office following successful monitoring on the PCM-1B. OPS 6, who also cleared the PCM-1B, left FB-Line at approximately 1130 hours and reported to another work location. OPS 1 and OPS 5 alarmed on the fifth level PCM-1B, indicating external contamination. An FB-Line RCO inspector responded to the PCM-1B alarms. As discussed in Section 2.1.3 below, RCO surveyed OPS 1 and OPS 5 and detected external contamination.

2.1.3 Emergency Response

Personnel Status

OPS 1 and OPS 5 alarmed on the fifth level PCM-1B, indicating external contamination. An FB-Line RCO inspector responded to the PCM-1B alarms. RCO surveyed OPS 1 and detected 1000-2000 dpm alpha/100 cm^2 on the front of the modesty shorts. RCO also surveyed OPS 5 and detected 1000 dpm alpha/100 cm^2 on the left palm. (Table 2-1 summarizes personnel radiological status during emergency response.)

At approximately 1145 hours, OPS 5 and OPS 1 were escorted to the third level RCO office, joining five of the six personnel who had successfully monitored on the fifth-level PCM-1B (OPS 2, OPS 3, OPS 4, RCO 1, and RCO 2). RCO resurveyed OPS 5 and reported the same levels as found when OPS 5 was surveyed on the fifth level. OPS 1 was also resurveyed, and 2000-5000 dpm alpha/100 cm^2 was detected around the face. OPS 1 blew his nose and a survey of the material indicated positive for alpha contamination. The five individuals who had successfully monitored on the PCM-1B were also surveyed, with negative results. All seven of the individuals were transported to the 221-F-Canyon facility for nasal and saliva smears and possible decontamination.

At approximately 1215 hours, the seven individuals were split into two groups. The two individuals with confirmed skin contamination were sent to F-Canyon's second level decontamination room. These two individuals were also found to have positive nasal smears. The second group (OPS 2, OPS 3, OPS 4, RCO 1, and RCO 2) was initially sent to the RCO count room on F-Canyon's first level. OPS 2 was subsequently sent to the second-level decontamination facility because skin contamination ranging from 1000-3000 dpm alpha/100 cm^2 was detected in the face/neck area and he was also found to have positive nasal smears. No external contamination was detected on OPS 3, OPS 4, RCO 1, or RCO 2. However, OPS 3, OPS 4, and RCO 1 were found to have positive nasal smears. At approximately 1245 hours, OPS 6 and three WSI-SRS personnel (WSI 1, WSI 2 and WSI 3) who had interacted with the affected individuals were surveyed in the F-Canyon first-level RCO count room and found to have no external contamination. WSI 2 was found to have a positive nasal smear.

At approximately 1300 hours, OPS 1, OPS 2 and OPS 5 were transported to F-Area medical for chelation consultation. All three accepted chelation. As personnel completed medical treatment, they were transported back to the 221-F-Canyon facility for decontamination. At approximately 1430 hours, OPS 3 was transported to F-Area medical for chelation consultation. OPS 3 declined chelation. At approximately 1500 hours, WSI 2 was transported to F-Area medical for chelation consultation. WSI 2 declined chelation and was subsequently released from medical. At approximately 1600 hours, OPS 3 was surveyed by RCO at F-Area medical and contamination levels of 500–1000 dpm alpha/100 cm^2 were detected in the head/hair area. OPS 3 was transported back to the 221-F-Canyon Facility for decontamination.

At approximately 1400 hours, RCO 1, RCO 2 and OPS 4 were transported to H-Area medical for chelation consultation. OPS 4 accepted chelation while RCO 1and RCO 2 declined chelation. RCO 1, RCO 2 and OPS 4 were surveyed by RCO at H-Area medical and external contamination was detected on all three: 1000 dpm alpha/100 cm^2 contamination was found in RCO 1's hair, 600 dpm alpha/100 cm^2 was found in RCO 2's hair, and 800–2000 dpm alpha/100 cm^2 was found on OPS 4's shirt and cap. RCO 1, RCO 2 and OPS 4 were subsequently transported to the 221-HB-Line facility for decontamination.

Both groups were successfully decontaminated at their respective locations and subsequently released to F-Area medical. Instructions and bioassay kits were provided to all personnel and they were released for the day at approximately 2000 hours.

Table 2-1. Personnel Radiological Status during Emergency Response

Position	Work Location	Positive Chest Count?	Positive Nasal Smear?	External Contamination Detected?
OPS 1	Vault/ Vestibule	Yes	Yes	Negative (at door). 1000-2000 dpm alpha/100 cm^2 (shorts) following PCM-1B Alarm. 2000-5000dpm alpha/100 cm^2 (face) FB-Line third-level RCO office.
OPS 2	Vestibule	Yes	Yes	Negative (at door). Negative PCM-1B. Negative FB-Line third-level RCO office. 1000-3000 dpm alpha/100 cm^2 (face/neck) 221-F-Canyon first-level RCO count room.
OPS 3	Vestibule	No	Yes	Negative (at door). Negative PCM-1B Negative third-level FB-Line RCO office. Negative 221 F-Canyon first-level RCO count room. 500-1000 dpm alpha/100 cm^2 (head/hair) F-Area medical.
OPS 4	Vestibule	No	Yes	Negative (at door). Negative PCM-1B Negative third-level FB-Line RCO office. Negative 221-F-Canyon first-level RCO count room. 800-2000 dpm alpha/100 cm^2 (ball cap and shirt) H-Area medical.
OPS 5	Vestibule	Yes	Yes	Negative (at door). 1000 dpm alpha/100 cm^2 (left palm) following PCM-1B alarm.
OPS 6	Fourth/ Third Level	No	No	Negative (at door). Negative PCM-1B. Negative 221-F-Canyon first-level RCO count room.

Position	Work Location	Positive Chest Count?	Positive Nasal Smear?	External Contamination Detected?
RCO 1	Vault/ Vestibule	Yes	Yes	Negative (at door). Negative PCM-1B Negative third-level FB-Line RCO office. Negative 221-F-Canyon first-level RCO count room. 1000 dpm alpha/100 cm2 (hair) H-Area medical.
RCO 2	Vestibule	No	No	Negative (at door). Negative PCM-1B. Negative third-level FB-Line RCO office. Negative 221-F-Canyon first-level RCO count room. 600 dpm alpha/100 cm^2 (hair) H-Area medical
WSI 1	Third Level	No	No	Negative 221-F-Canyon first-level RCO count room.
WSI 2	Third Level	No	Yes	Negative 221-F-Canyon first-level RCO count room.
WSI 3	Third Level (Supervisor)	No	No	Negative 221-F-Canyon first-level RCO count room.

Facility Status

The HVAM alarm for the vault was received in the Precipitator Control Room at approximately 1047 hours. The Operations Command Center logged the alarm at 1055 hours. Alarm Response Procedure 221-FBL-ARP-F390-716B-HA, *High Alpha*, and Abnormal Operating Procedure (AOP) FBL-1.009, *Response to Inoperable or Alarmed Constant Air Monitors (U)*, were invoked. Following receipt of the alarm, the Shift Operations Manager consulted with the Operations First Line Supervisor responsible for the job. They discussed the impact that the alarm condition would have on security requirements.

The Operations Command Center was informed of the personnel contamination cases at 1200 hours, after OPS 1 and OPS 5 were found contaminated in the fifth-level PCM-1B. The Shift Operations Manager implemented AOP-FBL-8.008, *Responding to Personnel Contamination Cases (U)*. WSI-SRS was directed to restrict access to FB-Line at the second- and sixth-level entry control facilities, and surveys were initiated by RCO to determine if any spread of contamination had occurred. By 1235 hours, RCO had determined that no contamination had been spread to the fifth or sixth levels and these areas could be maintained as Radiological Buffer Areas. Low levels of surface contamination were found on the third level near a door, and the third level was posted as a CA. A rollback team was dispatched to clean up contamination on the third level, and by 1545 hours, the third level had been cleaned up and rolled back to its normal Radiological Buffer Area status. Normal access to the facility was restored after contaminated areas had been cleaned up, surveyed and returned to Radiological Buffer Area status. Access to the stairwell leading to the vault remained restricted to isolate the accident scene.

2.1.4 Investigative Readiness

WSRC took appropriate action following the accident to preserve the integrity of the accident scene, collect evidence, and prepare for both an internal investigation and a possible DOE accident investigation. WSRC took statements from affected individuals within 24 hours of the accident. This action was deemed appropriate by the Board.

On September 22, 1999, the Board sent a letter to the Vice President, WSRC Nuclear Materials Stabilization and Storage Program. The Board took administrative control of all evidence associated with the FB-Line accident. The Board also requested that WSRC develop a formal process for evidence control, since most of the evidence was contaminated or potentially contaminated. The Board requested that all evidence be maintained in a safe, undisturbed configuration until the Board released control of the evidence. The Board also requested a complete, itemized list of evidence, utilizing the format identified in Revision 2 of the DOE Workbook, *Conducting Accident Investigations*. On October 6, 1999, the Board received the "FB-Line Control of Evidence" procedure and an itemized list of evidence.

2.1.5 Response to Bioassay Results

Thirteen individuals were placed on a special bioassay program as a result of the September 1, 1999, accident. This included the eight individuals from the work location (OPS 1, 2, 3, 4, 5, and 6, and RCO 1 and 2), three WSI-SRS individuals who interacted with the eight (WSI 1, 2, and 3), and two additional RCO inspectors who decontaminated the survey instrumentation used at the work site (RCO 3 and 4). Bioassay protocol included chest counts, submittal of 24-hour urine samples, and fecal samples.

At least seven intakes of radioactive material occurred as a result of this accident, based on positive fecal sample screening results. Four of these seven individuals had positive chest counts. Preliminary dose estimates for these four individuals were calculated using internationally accepted dosimetry models that describe the intake, retention, and excretion of a radioactive material in an idealized Reference Man; the first two chest count data points; the indicated ratio of plutonium to americium; and chest wall thicknesses calculated by the chest counting system software algorithm. These estimates (shown in Table 2-2) were communicated to the four personnel on September 9, 1999. Subsequent to the preliminary dose calculations, actual chest wall thicknesses for the four individuals were determined at the Medical College of Georgia, and additional chest count data were gathered for those continuing to exhibit results above the counting system minimum detectable activity. Using the actual chest wall thicknesses, the additional chest count data, internationally accepted dosimetry models, and the indicated ratio of plutonium to americium, the dose of record (also shown in Table 2-2) for these four individuals was calculated and provided to the individuals on January 4, 2000. For an independent review of the dose estimates provided on September 9, 1999, the Board requested an analysis of the bioassay data from an outside expert in the field of internal dosimetry, specifically that of the dosimetry of transuranics. Results of the independent analysis are discussed in Section 2.1.6 below.

Because of its insoluble nature, the amount of material exhibited in most of the individuals' urine samples was below the decision level for plutonium. As a result, urine samples provided by the 13 individuals were sent to the Los Alamos National Laboratory for Thermal Ionization Mass Spectrometry (TIMS) analysis. The TIMS analysis counts the number of Pu-239 and Pu-240 atoms present in each sample, and is approximately 40 times more sensitive than the alpha spectroscopy analysis technique. The TIMS analysis confirmed the insoluble nature of the material.

Due to a lack of confidence in the ability of the site's existing fecal sample processing technique to get the insoluble plutonium into solution for subsequent analysis, the SRS bioassay laboratory chemist, working in conjunction with a chemist from the SRS Central Analytical Laboratory, developed a new dissolution technique based on dissolution of soil containing plutonium. For an independent review of this new technique, the Board requested assistance from a DOE senior research chemist at the Radiological and Environmental Sciences Laboratory in Idaho. The chemist reviewed the procedure for the new technique and prepared two artificial fecal samples spiked with NIST-traceable insoluble plutonium and americium. These two samples were delivered to the SRS bioassay laboratory and put through the new dissolution technique and subsequent analysis. Test results were compared against the DOE Laboratory Accreditation Program performance criteria (i.e., relative bias of −25% to +50% and relative precision of ≤40%) for radiobioassay and found to be satisfactory. The bioassay laboratory began analyzing fecal samples from the 13 personnel placed on the special bioassay program. Completion of the analysis, initially expected by December 31, 1999, was delayed due to equipment problems in the bioassay laboratory. At the time of this report, it was estimated that sample analysis and subsequent calculation of any dose of record for the remaining individuals would be completed by the end of March 2000.

Bioassay data will continue to be collected and analyzed for the affected individuals. Dose assignments may be revised either upward or downward when warranted by the analysis of the data.

Table 2-2. Dose Estimates and Dose of Record

	September 9, 1999, Estimates	January 4, 2000, Dose of Record
	Preliminary CEDE (rem)	**Final CEDE (rem)**
OPS 1	8.8	1.5
OPS 2	16.1	6.7
OPS 5	5.4	2.0
RCO 1	2.0	1.6

2.1.6 Validation of Dose Assessment

To validate the preliminary conclusions reached by WSRC on September 9, 1999, the Board secured the services of an expert in the field of internal dosimetry, specifically that of dosimetry of transuranics. This expert previously validated WSRC conclusions and examined the methods, techniques, and facilities used to arrive at these conclusions as part of the 1997 DOE Type B accident investigation of a plutonium intake at the SRS F-Canyon. The independent assessment of the data concluded that the WSRC approach was adequate and met the Board's expectations for evaluation of dose resulting from the internal deposition of radioactive material.

2.2 PHYSICAL HAZARDS, CONTROLS, AND RELATED ACTIVITIES

2.2.1 Bagless Transfer System

In 1997, a bagless transfer system was designed and installed in FB-Line for packaging plutonium metal, with a bagless can meeting the requirements of DOE-STD-3013-94, *Criteria for Preparing and Packaging Plutonium Metals and Oxides for Long-Term Storage*, as the inner can of a two-can configuration.

A Readiness Assessment Plan for Startup of the FB-Line Bagless Transfer Process was developed and approved on July 2, 1997. The assessment was completed on August 12, 1997, all pre-start findings were corrected, and the authorization to start bagless transfer operations was issued on August 27, 1997.

Bagless Canister Weld Qualification Development Program

Facts

- The bagless canister design consists of an American Iron and Steel Institute Type 304L stainless steel cylindrical canister (*Figure 2-2*). The process calls for the canister to be back-filled with helium, automatically seal-welded to an internal hollow plug using a single-pass, fillerless Gas Tungsten Arc/Tungsten Inert Gas weld, and cut into two parts, with one part remaining as the glove box seal and the other part (containing plutonium) placed into storage.

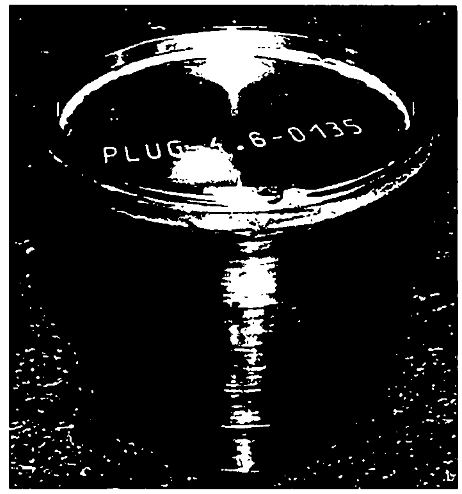


Figure 2-2 Representative Bagless Can

- A qualification program was developed to ensure the functional integrity of the welding process and the canister-cutting process equipment. Thirty-six canisters were tested in accordance with the requirements of DOE-STD-3013-94 (WSRC-TR-96-337). Acceptance criteria included visual defect examinations, leak rate, burst strength, compression testing, crush testing, and metallography. The results qualified the bagless transfer system welding/cutting processes and equipment.

Analysis

The SRTC qualification program for the welding program was accomplished in accordance with the requirements of DOE-STD-3013-94. The welding parameters established during the development program produced bagless cans that met or exceeded DOE-STD-3013-94 requirements. Although there was no indication that a can with a defective weld would be produced by the system, the welding specialists interviewed all agreed that any welding system is not 100 percent effective in producing good welds. Weld inspection techniques and equipment are used to identify defective welds so they can be repaired, and adequate weld inspection must be an integral part of any welding system.

Bagless Transfer Operations

Facts

- In the FB-Line production operation, automated welding and cutting functions were performed by one of the two facility operators in the room, and each step was recorded by someone outside the room. One of the two operators also performed welded canister visual inspection and leak tests. Visual inspection was performed while the operator wore an air-fed hood. OPS 3 stated during an interview that the air-fed hood adversely affected operator visual acuity.
- The first two bagless transfer operators were trained and qualified using the system at SRTC, prior to its transfer to FB-Line. Subsequent operators were trained and qualified via On-the-Job training. Training consisted of viewing and discussing a bagless transfer system video, and demonstrating competence with two procedures: SOP-221-FB-1757-NS, *Storing Buttons*

in the Bagless Transfer Cabinet (U), and SOP-221-FB-1753-NS, *Reworking and Repackaging Buttons Using the Bagless Transfer System.*

- OPS 3 was the first operations person to complete the training, and he became the trainer for the other operations personnel. OPS 3 stated that he participated in welding about 90 percent of all bagless transfer cans.
- Numerous production bagless transfer system canisters were welded before the September 1, 1999, accident. Operators who performed canister welds stated during interviews that five canisters exhibited weld problems during production. In one case, the internal plug was not properly positioned during welding, and in another case, the helium hose was not connected to backfill the canister prior to welding. The other three weld problems triggered a welder alarm, visually looked bad, or failed a leak test. These canisters were cut apart and the contents were repackaged without any formal root cause analysis of the weld defects.

Analysis

Operator training for the bagless transfer system was thorough in equipment operation and maintenance. The equipment was considered to be relatively automatic, with process upsets detected by the controlling computer, which sounded the appropriate alarm. One facet of the training that was never developed and taught was the visual inspection of welds. Per SOP-221-FB-1753-NS, operators were to "inspect weld on canister for abnormalities (gaps, holes, globules)." Photographs of example weld defects were never developed to train operators on visual weld examinations. In one case, a can that passed visual inspection but failed a leak test was reworked without analyzing the nature and cause of the defect. As a result, the opportunity to determine the cause of the weld defect was missed.

Can FBL-BC-00279 Weld Integrity Checks

Facts

- Can FBL-BC-00279, the fifth can to be packaged on September 1, contained a weld non-conformity/defect (*Figure 2-3*).
- Production records disclosed that on July 14, 1998, can FBL-BC-00279 was welded and cut by one operator, and inspected by a second operator (OPS3). Three checks of weld integrity were performed on can FBL-BC-00279 before it was placed in a vault for storage, as provided for by operating procedures. These checks, performed in sequential order, were (1) visual inspection by the equipment operator, (2) non-helium volumetric gross leak test, and (3) helium leak test.

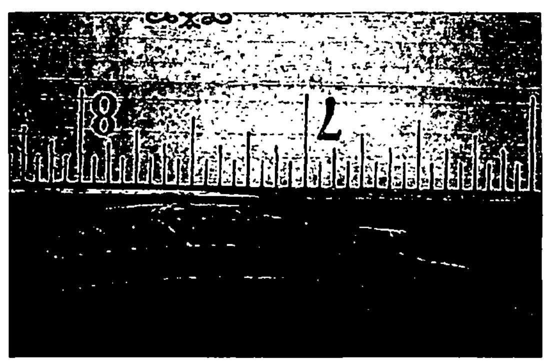


Figure 2-3 Weld Defect

- Visual examination failed to detect the weld defect in can FBL-BC-00279.
- The Volumetric Gross Leak Test and Helium Leak Test Systems failed to detect the weld defect.
- Interviews disclosed that canisters were also visually inspected and checked for contamination upon acceptance into the storage vault.

- A failure analysis of the FB-Line bagless transfer can FBL-BC-00279 was completed by SRTC in January 2000 (G-TRT-A-00001, *Failure Analysis of the FB-Line Bagless Transfer Can (U)*). This report concluded that the weld defect was present when the weld checks were made.
- The leak check equipment and instrumentation had not been calibrated since their initial introduction into the bagless transfer system.

Analysis

The SRTC evaluation of the weld defect concluded that the weld defect was created at the time of welding, not as a result of subsequent handling. The hole and bulge discontinuities should have been evident during the visual examination prior to the leak test. Failure of the visual inspection may have been caused by the obstructed view afforded by the air-fed hood worn by the operators. A successful visual weld inspection relies on an unobstructed, magnified view of the weld, elements that were not provided in the room where the cans were welded. A direct pathway from the plutonium metal to the can exterior existed at the time of inspection. The lack of contamination release during the leak tests and subsequent transport to the vault supports the observation that oxide was not present. Only during the 14 months of storage in the vault was oxide generated that was released by movement of the can. The lack of a contamination spread from the vented can prior to movement can be attributed to the near stagnant nature of vault ventilation.

The failure of the non-helium Volumetric Gross Leak Test to detect the weld defect cannot adequately be explained. The test was specifically designed to identify large leaks that would have allowed helium to escape from the can. The Volumetric Gross Leak Test vacuum would have effectively removed any remaining helium, thus preventing the Helium Leak Test System from detecting the flaw. The two leak tests were designed to complement each other, with the gross leak test identifying large leaks and the Helium Mass Spectrometer Leak Test identifying very small leaks. Calibration using a good welded can and a leaking can, which was performed prior to and following the leak test of can FBL-BC-0279, should have demonstrated operability of the equipment and the expected vacuum reading of the meter.

The multiple levels of inspection and testing performed on the bagless can should have detected the weld defect. The Board considered three broad categories in which the weld integrity checks could have failed: human factors, quality assurance, and equipment malfunction. Examples of possible reasons for weld check failure due to human factors include operator did not perform visual inspection and leak checks; operator did not have clear, unobstructed view of weld; operator distracted by plant operation/events during inspection and testing; leak check equipment operated incorrectly (standard can tested instead of product can); and communication between operator and recorder inadequate (completion of tests recorded in error). Examples of possible reasons for weld check failure related to quality assurance include operator not adequately trained for performance of inspection and testing, and inadequate maintenance and calibration of leak test equipment. Weld check failure could also have occurred due to failure of the leak test equipment.

The Board could not conclusively determine the reason that the multiple weld checks failed to detect the weld defect on the bagless can.

Weld Defect Failure Analysis

Facts

- A failure analysis of the FB-Line bagless transfer can was completed by SRTC in January 2000 (G-TRT-A-00001, *Failure Analysis of the FB-Line Bagless Transfer Can(U)*). The Board closely followed the analysis of the failed bagless transfer can by observing non-destructive and destructive analyses, attending peer review meetings of the results, and reviewing the draft and final report. The Board concurs with the recommendations contained in the report. The remaining facts in this section summarize the report's key findings.

- An oval-shaped hole with an average diameter of approximately 0.1 inches was located in the can weld at the second of three tack welds made prior to the overpass closure weld.
- The weld hole existed when the weld was completed.
- A lump of excess weld metal was adjacent to the hole.
- The chemical composition of the can wall, plug and closure weld was within procurement specifications.
- No contaminants were found on the can, in the weld bead or in the slag-like particle attached to the weld bead.
- Other than the anomaly region of the second tack weld, the closure weld was satisfactory.
- There was no organic material in the weld zone.
- The grit-blasting process used on the can and plug left embedded material that could be partially absorbed into the weld bead.
- The can and plug diameters were consistent with procurement specifications. Receipt inspection records indicate can FBL-BC-00279 was 4.514 inches in diameter and plug #425 was 4.507 inches in diameter.
- The appearance of the weld hole is consistent with a blow-out during the welding process.
- Metallography revealed variations in the elevation and depth of penetration of the second tack weld. Portions of the tack weld were not reconsumed by the overpass weld.

Analysis

SRTC's weld failure examination utilized all available investigative capability. The Board's review of this report showed the investigation to be thorough, with no further outside analyses suggested. SRTC utilized the expertise of three outside consultants with specific expertise in weld technology and failure analysis. There was consensus between the consultants and SRTC material experts as to the nature of the defect and the factors that could have caused the weld failure. Based on analysis by the Board and its consultants, the Board concurs in the results of the SRTC analysis.

The 0.1-inch hole in the can weld provided a clear path from the plutonium metal to the can exterior. The oxide-free metal as originally packaged appears to have insufficient aerosol-sized oxide to release contamination, even with a relatively large hole. This is further borne out by the 14-month storage in the vault without detectable oxide particle release. The detectable release occurred because the can was moved.

The hole in the weld was made during the welding process and was not opened or enhanced by subsequent operations. The scanning electron microscope showed the weld bead around the hole to be solidified, with no evidence that anything had previously covered or obstructed the hole.

The weld thinning before the hole is characteristic of a weld 'blowout." The defect originated with the original tack weld, which was not covered by the overpass closure weld. The remainder of the can weld was satisfactory.

Measurement was made of the plutonium isotopic composition in the weld defect to verify it matched the plutonium isotopic composition of the vault air sample filters. The isotopic compositions matched. The chemical composition of the can wall and plug were also measured and found to be consistent with procurement specifications. The can and plug dimensions were also consistent with the procurement specifications. The only procurement issue of concern is the requirement to grit-blast the can wall and plug. Grit-blasting appears to leave embedded material on the metal surfaces which can be partially absorbed into the weld bead. The rest of the material ends up in slag-like particles adjacent to the weld. The grit-blast material is primarily calcium, aluminum, and silicon oxides. The purpose of requiring the vendor to grit-blast the cans and plugs is to enhance heat transfer away from the weld area.

The potential of weld contamination from organic materials such as vacuum grease was evaluated by welding spare cans with grease contamination that could come from the glovebox vacuum seal for the plug insertion rod and helium purge system. The grease had no effect on the ability of the welder to make a satisfactory weld. No carbon or other contamination was found in the weld or area adjacent to the weld defect.

Unusual machine grooves were observed on the plug underside adjacent to the hole. These scrape marks are suspicious, but appear to have no connection to the weld failure.

The gap between the can wall and the plug was analyzed. The potential exists for an 0.008-inch gap to occur with the procurement specifications. An additional gap increase could occur because of the 0.01-inch tolerance on can diameter ovality. Measurements on the failed can showed contact was made between the can and the plug at three points and that the gap between the two components was well within gap tolerence.

SRTC's report discusses the potential root cause of the weld failure. The report concludes that there is no evidence to identify a single condition as the root cause. The report identifies overpressurization of the can during welding (possibly due to lack of venting) as the most likely cause of the weld failure. This conclusion has been reviewed by the Board and the Board is in agreement with SRTC.

2.2.2 Storage Vaults

Vault Surveillance Program

Facts.

- A surveillance program for FB-Line vault contents was implemented in December 1996 (WSRC-TR-96-0413, *A Surveillance Program to Assure Safe Storage of FB-Line and Building 235F Vault Materials (U)*).
- An FB-Line surveillance program was initiated on February 12, 1999, to survey the storage cans produced by the bagless transfer system packaging program (NMS-ETS-99-0017, *Vault Surveillances for Plutonium Metal Packaged in Bagless Cans (U)*).
- Approval was given on August 27, 1997, to start-up the bagless transfer process in FB-Line. The surveillance program required that each bagless can be weighed once between its first and fifth year. Thereafter, the bagless cans were to be weighed once every 5 years.
- No specific surveillance was carried out on the failed bagless can between the date of its placement in the vault in July 1998 and the date of the accident.

Analysis

WSRC-TR-96-0413, *A Surveillance Program to Assure Safe Storage of FB-Line and Building 235F Vault Materials (U)*, described the overall surveillance program for materials stored in the FB-Line and Building 235-F vaults. Bagless transfer system cans had not been produced at that time and were not included in the report, but were addressed in a subsequent document.

WSRC-TR-96-0413 documented a risked-based approach to surveillance, with materials grouped according to their physical characteristics and specific pertinent information. From vulnerabilities common to each group, the most significant perceived vulnerability was selected. Materials were then categorized according to significant vulnerabilities, allowing the specification of surveillance to detect and prevent these failures for each category. Material categories from the DOE Complex-wide Plutonium Vulnerability Assessment were used to rank vault holdings according to perceived risk. A surveillance measure and indicator, and a surveillance frequency, were established for each material category. WSRC personnel indicated that complete surveillance of high-risk categories had been completed and repackaging had been carried out where appropriate.

WSRC-TR-96-0413 included a combination of random verifications required for Material Control and Accountability (MC&A) purposes and weighing of specific items considered to have a higher level of suspicion or concern. All containers were visually inspected for signs of adverse condition during physical inventories, but were not necessarily touched or rotated. Radiography was also used in FB-Line to inspect stored material. High-Efficiency Particulate Air-filtered cans were routinely inspected to ensure filter operability. Inspection was also routinely carried out for contamination on the outside surfaces of storage containers, especially near seal areas. Normal surveillance for surface and airborne contamination in the vault was also considered part of the stored can surveillance program.

Vault Safety Analysis

Facts

- FB-Line's Safety Analysis Report DPSTSA-200-10, *Accident Analysis*, Section 5.1.5, addressed low energetic events. The report included analysis of a pressurization/overpressure event that could cause the movement of liquid or solids into unintended locations.
- The Safety Analysis Report considered pressurization/overpressure in a storage vault to be a credible event, with a frequency of 1×10^{-5} occurrences per hour (i.e., once every 11.4 years). The report analyzed this event for release via the stack, but not for worker protection.

Analysis

The bagless transfer system can failure can be considered a low-energetic event. The concern related to the FB-Line Safety Analysis Report's pressurization/overpressure analysis was that the overpressure might mean the normal confinement boundaries for plutonium are lost, releasing plutonium to an environment outside its normal primary confinement. As noted, the Safety Analysis Report considered pressurization/overpressure in a storage vault to be a credible event. The specific scenario involved in the September 1 accident (i.e., hole in a can and subsequent handling by an operator) was not explicitly analyzed.

Plutonium Storage Standards

Facts

- DOE Technical Standard DOE-STD-3013-94 was issued in December, 1994, establishing criteria for 50-year storage of stabilized metals and oxides containing more than 50-mass-percent of plutonium. The standard has been revised twice, and is currently identified as DOE-STD-3013-99, *Stabilization, Packaging and Storage of Plutonium-Bearing Materials.*
- DOE developed criteria for interim storage of plutonium-bearing materials to provide guidance on the interim safe storage of plutonium-bearing solid materials for a period of 20 years or less (*Criteria for Interim Safe Storage of Plutonium-Bearing Solid Materials, November 1995*). These criteria were intended to provide a consistent approach for DOE as it

carries out the Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 94-1, dated February 28, 1995. The interim criteria were promulgated by a transmittal memorandum (Curtis to Manager, Savannah River Operations Office, dated January 25, 1996, *Criteria for Interim Storage of Plutonium Bearing Materials*). The transmittal memorandum required the development of a site-specific technical basis and a surveillance program. Site-specific evaluations of local storage arrangements were required because of the general nature of the criteria.

- DOE-SR did not direct WSRC to develop site-specific technical basis.
- The bagless can does not meet the double containment requirement as defined in the interim criteria.
- Other containers in the FB-Line vaults meet the interim criteria definition of double containment.

Analysis

In response to the memorandum transmitting the interim criteria, DOE-SR directed WSRC to develop only a surveillance program, and WSRC prepared a surveillance plan. DOE-SR did not specifically direct WSRC to prepare a site-specific technical basis, and one was not prepared. Because of the general nature of the criteria for interim storage of plutonium bearing materials, each site was asked in the memorandum transmitting the interim criteria to evaluate its unique situations for plutonium storage against the criteria and prepare a site-specific technical basis. It would be expected that such a technical basis would either document compliance with, or justify any deviations from, the interim criteria. In addition, DOE-SR and WSRC may have missed another opportunity to consider worker safety and/or to re-examine the quality assurance needed for the production of bagless cans.

2.2.3 Quality Assurance

Facts

- The bagless can was functionally classified as general service. Through application of graded quality assurance, general service items have fewer and less rigorous controls than safety significant items. The bagless transfer system was considered safety significant during the qualification process, and had a written quality assurance plan (WSRC 22472-TT/QAP Rev.2, *Qualification of the Bagless Transfer System*). The SRTC Quality Engineer who prepared the quality assurance plan stated he had no communication with line operations concerning the transition from development to operations, and the kinds of quality controls needed during and after the transition to production mode in FB-Line.
- Bagless can welding was not subject to special process quality requirements during production, and weld processing parameters could not be determined for the failed can because there were no permanent records. WSRC 1Q, *Quality Assurance Manual*, defines "special process" as a process, the results of which are highly dependent on the control of the process or skill of the operators, or both, and in which the specified quality cannot be readily determined by inspection or test of the product.

Analysis

Managers stated during interviews that canister integrity was essential to the overall vault safety strategy, particularly with regard to worker protection. Because the welded can provided the only barrier between the plutonium and a worker, classifying the bagless cans as general service was not consistent with management's overall safety strategy as quality assurance requirements were discretionary for the responsible program. Applying a rigorous quality assurance plan to can production based on its significance to worker safety would have improved the likelihood that the flawed can would have been detected. Additional controls could include using qualified weld inspectors, using qualified non-destructive evaluation inspectors, ensuring inspectors are independent, and defining weld parameter printouts as quality records.

Because the bagless transfer system was considered safety significant during the qualification program, a rigorous quality plan was applied. However, during production, the can was considered general service and quality control was significantly reduced.

2.2.4 Ventilation System

Facts

- Ventilation in the vault and vestibule was near stagnant when the vault door was open. This condition was noted by numerous personnel interviewed and was documented in two air studies (ESH-HPT-94-0219, Rev. 1, September 13, 1994; and EHS HPT-98-0517, October 20, 1998). Air was not supplied to either the vault or vestibule (only vault exhaust was provided). A fire protection project replaced the floor hatch in the vestibule. Additionally, vault supply ducts were blanked off (FBL-TMC-96-014), the supply duct for the vestibule was decoupled from the supply duct for the vault, and air was drawn through cracks and crevices when the vault door was closed.
- The HVAM system engineer stated that HVAM does not provide representative or timely air sampling when stagnant air conditions exist. The engineer indicated the HVAM would not operate as per specifications if air exchanges do not exceed 10 to 12 exchanges per hour (ORNL-NSIC-65).
- Since 1994, airflow studies of the vault have indicated ventilation conditions are poor. During the Board's investigation, a project (GPP S-W 446, *Vault Air Supply*) was underway to provide interlocked dampers into supply air ducts for the vault and alternate ducted supply to the vestibule and stairway, but this project was not funded until Fiscal Year 2000.
- Respiratory protection was required in the vault, but not in the vestibule. Personnel stated during interviews that they believed they were safe in the vestibule and could not receive airborne contamination from the vault.
- WSRC management stated they believed the bagless cans would not leak and that the cans were essential to safety. During a mock-up of the accident, the leaking can was placed inside the vestibule for surveying. Based on interviews, this action also occurred during the accident and provided a source for airborne contamination in the vestibule.
- An oxygen and heat stress survey was performed by WSRC on August 5, 1999, for WSI-SRS as a result of an employee concern. The results indicated that the calculated heat index allowed unlimited work duration in the vestibule, with enforced water intake. This is the lowest level of control for heat stress. Oxygen levels were within normal ranges. The outside temperature on the day of the survey was 90 degrees Fahrenheit. During the Board's investigation, several interviewees indicated they felt the heat levels in the vault/vestibule were excessive during the summer months.
- No ventilation requirements were identified that had been applied to the vault and vestibule.

Analysis

The Board could not find a requirement for monitoring of airborne contamination when respirators were being worn, but did identify DOE/EH-0256T, *DOE Radiological Control Manual* (required by S/RID 11.02.02.002), which states, "Internal exposure should be reduced to the minimum practicable level and the following should be considered: Collecting representative airborne radioactivity samples and the time required for technicians or automated instruments to determine the airborne concentration of radionuclides may contribute to worker intakes of radioactivity."

The Board was also unable to locate a requirement for ventilation/air flow, but identified the following in ESH-HPT-94-0228, Rev. 2, *SRS Workplace Air Sampling & Monitoring Technical Basis Manual*: "Respiratory protection controls should only be implemented after all feasible engineering and administrative controls have been implemented and a potential for exposure to airborne radioactivity remains." The Manual also states, "Use of engineering and administrative controls... should be evaluated before allowing personnel, with or without respiratory protection, to enter areas with airborne radioactivity." In accordance with DOE/EH-0256T, *DOE Radiological Control Manual*, "...processes and activities with the potential for producing airborne radioactivity shall include engineering controls to limit releases whenever appropriate."

Near stagnant ventilation conditions could have allowed airflow from the vault into the vestibule through mechanisms such as turbulence created by operators passing between the vault and the vestibule. Though specific requirements were not identified for correcting many of the ventilation conditions existing in the vault and vestibule area, there was general agreement among the ventilation and instrumentation specialists consulted by the Board that conditions in the vault would not have ensured proper functioning of the HVAM. Many available engineered and administrative options would have mitigated the effects of poor ventilation, including a portable continuous air monitor (CAM) in the vestibule, "tell-tail" flow-indicating strips, and/or evacuation instructions for the HVAM alarm requiring exit from the vestibule as well as the vault. These or other options could have compensated for possible migration of airborne radioactivity from the vault to the vestibule, a slower than expected response to the HVAM, and delays in exiting the vestibule. These factors, including the near stagnant air, heat, and the location and functionality of the HVAM, should have been the basis for analysis supporting worker protection.

2.2.5 Conduct of Operations

Procedural Compliance

Facts

- A pre-job briefing was conducted for the September 1 material movement work and was documented on a record copy of the procedure. Supervisory personnel who conducted the briefing initialed for having discussed air monitoring alarms. However, personnel present at the pre-job briefing conducted for the September 1 work in the vault stated that the response to air alarms was not discussed.
- The Shift Operations Manager and RCO First Line Supervisor were not contacted when contamination levels of 2000 dpm alpha/100 cm^2 were found on the fifth can being packed on September 1.
- Interviews indicated the operator in the vault at the time the HVAM alarm occurred was not surveyed for contamination when he exited the vault to the vestibule.
- Individual cans processed in the vault on September 1 were not surveyed prior to being handled.
- Interviews indicated the RCO who performed initial entry into the vault on September 1 did not verify dose rates at the door where operators were stationed for the work being performed that day.
- An operator, wearing a full-face negative pressure respirator, re-entered the vault after the HVAM alarm without RCO permission.

- Facility personnel were unable to locate a completed copy of SOP 221-FB-8081, *Accessing High Radiation Areas (U)*, for the September 1 entry into the High Radiation Area (HRA) in the vault.
- WSI-SRS security police officers did not contact their supervisor upon receipt of the HVAM alarm.
- One operator in the vestibule was wadding up aluminum foil for placement in the shipping container. The placement of aluminum foil in shipping containers was an activity procedurally directed by the SOP in use in the work area at the time of the event (SOP 221-FB-1186-H-NS). The operator was wearing a labcoat.
- Two operators did not sign in on RWP 99-FBL-007 on September 1, 1999. Personnel are required to sign in each month on RWP 99-FBL-007 for routine entry into CAs for hands-off activities prior to entry.

Analysis

SOP 221-FAC-1459-A-NS, *Operations Pre-Job Briefing and Operator Duties (U)*, required a discussion of air monitoring alarms. The Board observed several pre-job briefings. During these briefings, radiological concerns in general, and air monitoring alarms in particular, were addressed in a cursory manner, in contrast to SOP requirements.

In accordance with SOP 221-FB-1186-H-NS, *Packaging Fissile Material in a 30-Gallon 6M Shipping Container for Shipment to Building 235-F (U)*, "Measurable contamination, as measured with portable survey equipment, is not expected. If measurable contamination is found the Shift Operations Manager and the RCO First Line Supervisor shall be contacted." Additionally, transferable contamination Suspension Guide Limits for RWP 99-FBL-216 covering the September 1 material handling operation were ≥5000 dpm alpha/100 cm^2 for work in the vault and ≥2000 dpm alpha/100 cm^2 for CA work. Although the can was in the vestibule, a CA, when 2000 dpm alpha/100 cm^2 was found on it, RCO and OPS supervisors were not notified.

AOP-FBL-1.009, *Response to Inoperable or Alarmed Constant Air Monitors (U)*, requires that after an affected area has been evacuated, RCO is to immediately begin personnel surveys to determine if personnel contamination or an assimilation was received by personnel in the area. All personnel interviewed indicated they considered the affected area to be the vault, and the operator's relocation from the vault to the vestibule satisfied the requirement to evacuate the affected area. Although the operator was not surveyed for contamination in the vestibule after leaving the vault, he remained in the vestibule and continued to work there in close proximity to other workers who had not been in the vault and who wore no respiratory protection.

RWP-99-FBL-216 specified, "In South Storage Area: RCO must verify dose rates at the [vault] door after door is opened." RWP- 99-FBL-216 specified, "In South Storage Area: RCO to survey all items to be touched by operators due to possible contamination levels of >2000 dpm alpha/100 cm^2." If RCO had surveyed the can before it was handled, as required, contamination on the defective can could have been detected while the can was in the vault. This could have prevented the source for the event from being moved into the vestibule.

In accordance with WSRC 5Q1.2-130, *Continuous Air Monitor – Particulate Airborne Activity Alarm Immediate Action*, "RCO supervision shall approve re-entry into the affected area(s) under the existing RWP (i.e., without requiring additional protective clothing and respiratory protection)." SOP 221-FB-1482, *FB-Line High Volume Air Monitor System Training*, is required to be conducted for all assigned FB-Line employees. This procedure requires personnel to leave the room immediately, report to RCO, and not enter without RCO permission. These requirements are also addressed in Radiation Worker II training. By not obtaining RCO permission to re-enter the vault, the Operator entered an Airborne Radioactivity Area (ARA) without allowing RCO to verify that his respiratory protection was adequate for the work area.

Required SOP 221-FB-8081 was either not completed, or the procedure was completed but could not be located. The Board reviewed three copies of SOP 221-FB-8081 executed for similar jobs the previous day, and found they were not properly executed. Although the procedures had been signed as completed and reviewed, two contained unsigned steps to verify that all personnel exited the HRA and verify the HRA door was locked. The third procedure contained an unsigned step to conduct a pre-plan meeting.

WSI-SRS Post Orders 3-4432 and 3-4433 (both Rev. 95-1) required personnel to "Call your supervisor for any of the following reasons... (1) All Emergencies." WSI-SRS Emergency Security Operations Procedure 2-201 requires that security police officers notify other security police officers in the area of any emergency alarm. Because WSI-SRS personnel in the affected area did not notify their supervisor of the HVAM alarm, the supervisor was not afforded an opportunity to notify other WSI-SRS personnel in the exit path.

DOE/EH-0256T, *DOE Radiological Control Manual*, (required by S/RID 11.06.01.030) states, "The use of labcoats as radiological protective clothing is appropriate for limited applications such as [hands-off tours or inspections]... Labcoats should not be used as protective clothing for performing physical work activities in CAs, HCAs, and ARAs." Per WSRC 5Q1.2-231, *Selecting Protective Clothing and Equipment*, "Labcoats shall not be used as protective clothing for performing physical work activities in CAs, HRAs, and/or ARAs." By performing hands-on work necessary to execute an operations SOP, the operator violated the RWP authorizing use of labcoats.

The numerous procedural violations that occurred before and during the accident significantly contributed to the event. Had the required surveys been performed, contamination may have been detected before the defective can was handled or before it was removed from the vault, preventing the intakes. Had proper response procedures been followed, the magnitude of the intakes could have been significantly reduced.

Abnormal Operating Procedures (AOP)

Fact

- AOP-FBL-1.009, *Response to Inoperable or Alarmed Constant Air Monitors (U)*, contains both requirements for responding to an air alarm and actions to take for failed equipment. In the procedure, actions for a failed HVAM or portable CAM are addressed before actions for a CAM alarm.

Analysis

Per WSRC 2S Procedure 1.6, *AOP/EOP Preparation*, "AOPs are developed for events that affect several plant systems, threaten the facility safety envelope, or require operator action to mitigate facility damage." In contrast, AOP 1.009 contains a mixture of casualty response actions and actions for inoperable equipment. Additionally, actions for an air monitor alarm are addressed after actions for an inoperable air monitor, an arrangement that could contribute to a mindset that attributes air monitor alarms to failed equipment rather than immediately treating all alarms as real.

HVAM Labeling/Training

Fact

- Training for operators and RCO inspectors was not conducted following change-out of the HVAM chart recorders. The recorder label and the recorder were inconsistent in how they identified the chart recorder sample points on which the vault HVAM was monitored (the label identified points by letters, while the recorder printed numbers).

Analysis

In accordance with WSRC 2S Procedure 5.11, *Equipment and Piping Labeling*, "Labels for equipment to be installed should be included in the work package for that equipment...". In this case, the recorder had recently been replaced, but the label was not changed to match the equipment. In addition, the recorder printed a series of dots that were difficult to discern from each other, and training was not conducted on the new recorders following installation. These factors contributed to confusion in reading and evaluating the HVAM recorder indication following its alarm.

Communications/Log Keeping

Facts

- The pre-job briefing for the September 1 material handling work did not include all involved personnel.
- The First Line Supervisor acted as the Shift Operations Manager's representative for the vault work. The First Line Supervisor, located on the third level, stated in an interview that he communicated with the operators in the vestibule by "tapping on pipes" to signal when it was time to send another shipping container to the vestibule.
- Interviews indicated that after the alarm, the various work groups in the vestibule did not brief or consult with each other during their response and egress. The RCO inspectors in the affected area did not communicate to other workers the airborne hazard to which they had been exposed, the potential for personnel contamination, or precautions that should be taken to prevent potential cross-contamination of others outside the event area during egress. The operators' primary concern was material security, but they did not communicate their intention to re-enter the storage location following the HVAM alarm. The Operations First Line Supervisor did not confirm conditions in the affected area or pursue status of the event from the work crew during their egress. He was concerned with vault security, but did not confirm radiological conditions in the affected area. He did not conduct briefings with the crew in the vestibule to confirm that the actions of AOP-FBL-1.009, *Response to Inoperable or Alarmed Constant Air Monitors (U)*, had been carried out. He also did not keep the Shift Operations Manager informed. The Shift Operations Manager Log documented the HVAM alarm at 1055 hours, but contained no additional entries regarding event status until 1200 hours, after personnel contamination had been confirmed.

Analysis

Per WSRC 2S Procedure 2.1, *Communications*, "When non-routine procedures or complex evolutions are planned, shift management shall conduct briefings on the evolution in advance. The briefing should include all personnel involved in the upcoming evolution or procedure." Operations and RCO personnel were represented at the pre-job briefing for the September 1 material handling work, but WSI-SRS personnel participating in the activity did not attend the pre-job briefing.

Per WSRC 2S Procedure 4.4, *Shift Routines and Operating Practices*, "Shift managers are responsible for: maintaining overall authority and responsibility for the direction and control of all activities within the facility... maintaining awareness of the facility status at all times and ensuring that facility equipment... is operated in accordance with written and approved procedures." Per WSRC 2S Procedure 2.1, *Communications*, "Operating directions are verbal instructions given to an operator that involve the operation of a system or piece of equipment.

These instructions must be brief and straightforward, otherwise written instructions must be used. Operating directions may be given face-to-face, by telephone, by radio, or through use of the public address system." The First Line Supervisor, acting as the Shift Manager's representative for the vault work, was unable to effectively discharge his obligation to direct the activities, maintain awareness of status and ensure operation in accordance with approved procedures with the limited communications established for the evolution. The lack of formal communication methods established for the evolution prevented the First Line Supervisor from being able to effectively communicate with the workers and direct the event response after the HVAM alarm.

Per WSRC 2S Procedure 2.1, *Communications*, "During transients or lengthy evolutions, have frequent briefings to ensure that all personnel are knowledgeable of facility status and planned activities." After the alarm, the various work groups in the vestibule did not brief or consult with each other during their response and egress. Each group had different concerns and priorities that were not communicated. The operators' primary concern was material security, but they did not communicate this concern or their intention to re-enter the storage location to the RCO inspectors following the HVAM alarm. The RCO inspectors knew that significant levels of surface and airborne contamination existed in the vestibule, and knew that the operator in the vault at time of the alarm had been exposed to significant airborne activity. However, they did not communicate this to the other workers to ensure that the exiting group recognized the potential for cross-contamination and took precautions to prevent cross-contamination. Following the alarm, the Operations First Line Supervisor could have talked with the crew face-to-face at the third-level Step-Off Pad, but did not. Because briefings between the work group and supervisor were not conducted, the supervisor did not understand the true nature of the event in progress and the hazards to which they had been exposed. He was thus unable to effectively direct the casualty response and could not carry out his responsibility to keep the Shift Operations Manager informed of the event in progress. The Shift Operations Manager did not keep abreast of the event and direct response actions as indicated by the gap of over an hour between the HVAM alarm and the next event entry, which was a status update.

Shift Routines and Operating Practices

Fact

- Telephone records and interviews indicated that after the HVAM alarmed, RCO 2 spent time on the phone with the HVAM room attempting to determine whether the alarm was real, while RCO 1 performed surveys of the vestibule.

Analysis

Per WSRC 2S Procedure 4.4, *Shift Routines and Operating Practices*, "Operations personnel respond to instrument indications and alarms until such indications and alarms are proven to be false. Facility, personnel, and environmental safety take precedence over facility production. The first response is a verification of system status (e.g., level, flow, temperature) by an independent method." In accordance with WSRC 5Q1.2-130, *Continuous Air Monitor-Particulate Airborne Activity Alarm Immediate Action*, "All CAM alarms should be treated as real. Never assume the alarm is false." Considerable time was spent determining whether the HVAM alarm was real or a spike, while means existed for verification by surveying the HVAM planchet.

Recordkeeping

Fact

- The facility could not provide a copy of SOP 221-FB-8081, *Accessing High Radiation Areas (U)*, which was required to be executed for the September 1 entry into the HRA in the vault.

- The Weld Chart Recorder records for cans made on July 14, 1998, including the defective can, could not be located.

Analysis

SOP 221-FB-8081 was either not performed, or the procedure was completed for the September 1 entry into the vault but could not be located. Weld Chart Recorder records were not required to be maintained, but could have been useful in ascertaining any indicated problems with the weld.

Job Hazard Analysis

Facts

- A Job Hazard Analysis (JHA) was not performed for the September 1 work in the vault.
- As of September 1, 1999, the facility had performed 45 JHAs.
- The FB-Line Operations Manager stated in an interview that JHA FBL-JHA-1999-0006 for job title "9975 Unpackaging, SOP 221-FB-1186-D-NS" at job location "221-FB-Line" was applied to the September 1 job because the work activity was similar.
- The JHA utilized for the September 1 work considered only common industrial hazards, such as foot injury, hand/finger injury, and back strain. It considered potential heat stress by having heat stress guidelines addressed in the pre-job briefing for current facility conditions.

Analysis

Per procedure, a JHA is not required for each activity performed in a facility. WSRC 8Q38, *Job Hazard Analysis Program,* establishes criteria for which jobs should have a JHA performed and priorities for completing them. FB-Line JHAs were developed on a priority consistent with guidance provided in WSRC 8Q38.

The JHA utilized for the September 1 work did not address the combination of hazards (i.e., the unpacking evolution in a hot environment in a CA/HRA/ARA) encountered in performing the September 1 job, and did not address concerns in an integrated manner incorporating the different work groups involved. The Board reviewed seven FB-Line JHAs addressing material handling/packing/shipping activities. Each addressed common industrial hazards, but did not address activities in context of the applicable environmental and radiological conditions where the work would be performed. Revision 1 of WSRC 8Q38 (the procedure in effect on September 1) stated, "This procedure provides guidance for performing safety evaluations to enhance the safety aspects of tasks/procedures not evaluated by existing processes (e.g., Work Clearance Permit, Radiological Work Permit...)".

Emergency Response

Facts

- The Operations First Line Supervisor responsible for the work in the vault did not supervise the evolution and did not keep abreast of job status as it progressed. He retained responsibility for the job, but was not at the job site and did not designate anyone at the job site as in charge. He did not direct and coordinate the exit of the affected individuals from the event scene, and none of the seven workers at the scene took charge when the event occurred.

- In responding to the accident, affected workers descended the stairs from fourth to third level and exited the CA on the third level using normal procedures. WSI-SRS security police officers were not warned that the individuals were potentially contaminated. No attempt was made to communicate with the workers as they exited to ascertain conditions in the accident area and to evaluate the potential that they might have been contaminated.

- The First Line Supervisor and Shift Operations Manager did not take action to confirm that the steps of AOP-FBL-1.009, *Response to Inoperable or Alarmed Constant Air Monitors (U)*, were completed following receipt of the HVAM alarm. The First Line Supervisor stated he relied on the workers' training to ensure they carried out applicable requirements.
- The facility drill program did not include all facility operations personnel. Two of the three operators involved in the event had been in the facility for 7 and 18 years, respectively, but stated they had not participated in facility Radiological Control drills other than as a victim. The First Line Supervisor was promoted to a supervisory position on shift in May 1998, and transferred to day shift in November 1998. He stated in an interview he had participated in only one drill since November 1998.

Analysis

WSRC 2S Procedure 1.3, *Procedure Compliance*, contains the following guidance on procedural usage: "Use ARPs [Alarm Response Procedures], AOPs, and EOPs according to the following guidelines: (a) Confirm alarm/emergency/abnormal condition; (b) Perform Immediate Actions; and (c) Confirm the procedure Immediate Actions, when conditions allow. NOTE: Unlike EOPs, personnel are not responsible for committing AOP and ARPs Immediate Actions to memory." WSRC 2S Procedure 1.3 also specifies that personnel should "refer to AOP during an abnormal condition to aid in mitigation of the condition and protect personnel or equipment." The WSRC individuals in the affected area were trained on the required response to a HVAM alarm, but were not required to have immediate actions committed to memory and did not have a copy of the applicable AOP.

Per WSRC 2S Procedure 4.4, *Shift Routines and Operating Practices*, "Shift managers are responsible for... taking any action, including shutting down the facility operation, necessary to protect the facility, personnel, the public, and environment under emergency conditions." The Operations First Line Supervisor, responsible to the Shift Operations Manager for the equipment handling evolution, did not position himself to allow him to direct and control the activities. The operators in the vestibule were experienced personnel who were counted on to execute the evolution in progress without direct supervision. The First Line Supervisor acted as a helper, rather than a supervisor, for the evolution. He positioned himself on the third level to supply empty containers to the vestibule because he did not have another person available to perform this support role. While on the third level, he did not maintain formal communications with the vestibule or keep abreast of job status. Following the alarm, the First Line Supervisor relied on workers' training to ensure they responded correctly to abnormal operating procedure requirements. None of the workers took charge following the alarm. Under abnormal conditions, RCO inspectors should take charge and ensure proper response when adverse radiological conditions are encountered. Although all personnel in the work area were Radiological Worker II qualified, RCO inspectors are expected to characterize workplace radiological conditions and provide firm direction when hazardous conditions are encountered. The potential for cross-contaminating other individuals along the exit path could have been reduced by either supervisory or RCO action in determining the nature of the event and coordinating exit by modifying normal security procedures.

Per WSRC 2S Procedure 3.3, *Facility Drills and Monitored Evolutions*, "The annual schedule should be organized to ensure that each shift participates in four (at minimum) drills per year...". The facility drill schedule provides for enough drills to satisfy this requirement for the rotating shifts, but does not address drill performance by the day shift operations crew. (WSI-SRS's role in drills and exercises is discussed in Section 2.3.3 of this report.)

2.2.6 Conduct of Radiological Operations

Work Activities

Facts

- The RCO inspector performing the initial entry vault survey limited the contamination survey to the floor area only.
- To support contamination surveys, the bagless cans were moved from their storage location (posted as a CA/HRA/ARA) and placed just inside the vestibule (posted as a CA).
- The bagless can was not completely surveyed prior to initiation of the decontamination effort.
- No radiological boundaries were in place at the vault (posted CA/HRA/ARA) to vestibule (posted as a CA) transition.
- An operator ascended and descended a ladder while wearing a labcoat, shoe covers and gloves as protective clothing. During the mock-up of the September 1 work activities, another operator was observed sitting in a chair and wadding up aluminum foil while wearing a labcoat, shoe covers and gloves as protective clothing.

Analysis

Moving items from their storage locations to the vestibule for contamination survey purposes was used as a personnel dose reduction technique. This practice was contrary to the requirements of the RWP controlling the work activities, which required items to be surveyed prior to handling by operators, and also increased the likelihood of spreading contamination. RCO 1 indicated during an interview, and demonstrated during the mock-up of the work activities, that the contamination survey of the bagless can in question was limited to only the top and upper portion of the sides of the bagless can prior to the initiation of the decontamination effort. A thorough survey of the can should have been performed to completely characterize the radiological hazard prior to decontamination and to ensure that the transferable contamination suspension guide limits specified on the RWP were not exceeded.

Interviews with several RCO inspectors indicated that limiting the initial contamination survey to the floor area of the vault, and moving items from the vault to the vestibule for contamination surveys, were standing practices passed from RCO inspector to RCO inspector, regardless of RWP requirements. Per 10 CFR 835 subpart 401(a), monitoring of individuals and areas shall be performed to document radiological conditions in the workplace, detect changes in radiological conditions and to detect the gradual buildup of radioactive material in the workplace. By not surveying the storage locations, an opportunity to identify contamination was missed.

Per WSRC 5Q1.1-518, *Radiological Posting*, boundaries for posted areas should consist of permanent structures (such as walls or fences) or specific radiological demarcations (such as yellow and magenta rope, chain, or tape). Physical barriers should be placed so that they are clearly visible from all directions and at various elevations, and should not be easily walked over or under except at identified access points. Barriers shall be set up such that they do not impede the intended use of emergency exits or evacuation routes. In cases where a barrier would interfere with personnel safety, the RCO Facility Manager may allow a 2-inch to 3-inch wide yellow and magenta line to be painted or taped on the floor. The presence of a visible boundary may have dissuaded personnel from moving the can into the vestibule prior to it being surveyed.

The operator's use of a labcoat, shoe covers and gloves for accessing the vestibule was supported by the levels of contamination maintained in the vestibule. Table 3-1 in WSRC Manual 5Q, *Radiological Control*, recognizes the use of labcoats, shoe covers and gloves for hands-off tours and inspections in areas with removable contamination at levels 1 to 10 times the values in Table

2-2 of the Manual (i.e., for alpha contamination, labcoats can be used with contamination levels up to 200 dpm). The observed activities (i.e., ascending and descending a ladder, sitting in a chair and wadding up aluminum foil) were inconsistent with the requirements of WSRC 5Q1.2-231, *Selecting Protective Clothing and Equipment.* This procedure indicates that use of labcoats as radiological protective clothing is appropriate for limited applications where the potential for personal contamination is limited to the hands, arms and upper portion of the body, but labcoats shall not be used as protective clothing for performing physical work activities in CAs, HCAs, and/or ARAs.

Radiological Control Alarm/Emergency Response

Facts

- No one in the vestibule took charge of the alarm response. Records indicated that 18-19 minutes elapsed between receipt of the HVAM alarm and exit from the vestibule.
- Several of the affected individuals were surveyed multiple times before external contamination was detected.
- The 11 personnel considered involved with the September 1 accident were processed through the 221-F personnel decontamination facility.

Analysis

None of the individuals in the vestibule indicated they were in charge during the alarm response. As previously discussed, each group had different concerns and priorities that were not shared between groups. This led to the group spending unnecessary time in the vestibule: 18-19 minutes elapsed between receipt of the alarm and exit from the vestibule. The Board conservatively estimated that within 5 minutes of receipt of the alarm, the group should have recognized the need to evacuate the vestibule. The 5-minute time estimate was based on the time necessary to perform a whole body frisk of the individual exiting the vault following receipt of the alarm (2-3 minutes), the time required to remove and survey the HVAM planchet (1 minute), and the time required to survey the filter paper on the air sampler in the vestibule (1 minute).

The seven individuals from the vestibule were eventually found to be externally contaminated with levels ranging from 500 to 5000 dpm alpha/100 cm^2. At the exit of the CA, the individuals performed a whole body frisk using a count rate meter with an alpha contamination probe, and did not detect any contamination. Four individuals were surveyed a number of times by RCO inspectors before contamination was detected. Due to its characteristics (e.g., short travel distance in air, does not readily penetrate through material), alpha radiation is difficult to reliably detect. The detector must be held within 0.25 inches of the surface being monitored and moved at a rate of 1-2 inches per second.

During interviews, several individuals expressed concern with the amount of time spent waiting in the 221-F Canyon personnel decontamination facility. Additional F-Area personnel decontamination facilities were not utilized. A review of WSRC Procedure 5Q1.2-203, *Handling Radiological Injuries, Contamination Cases, and Suspected Intakes of Radioactive Material,* indicated that personnel decontamination facilities were also available in 772-1F, 241-24F and 235-F.

Mock-up Issues

A mock-up of the activities that led to the September 1 accident was conducted on September 27, 1999. Participants stated that the mock-up was representative of the work practices employed during the September 1 accident. The Board observed the mock-up and noted the following concerns.

Facts

- Personnel were observed removing (but not replacing) security badges from inside protective clothing after entering the CA, to support logging into the electronic safeguards and security system (E3S). Personnel were observed donning a protective clothing hood and respirator after entering a posted CA. Personnel also demonstrated poor protective clothing doffing techniques at the exit of the CA. Specifically, personnel were observed not doffing per the sequence taught in radiological worker training and not following the practice of "dirty to dirty" and "clean to clean." The RCO inspector exiting the storage area demonstrated poor glove removal technique and also transitioned from a CA/HRA/ARA to a CA prior to completely removing the outer set of gloves. During the mock-up, as well as during interviews, RCO 1 repeatedly demonstrated a general lack of understanding of the work in progress, and a lack of knowledge of the work area (e.g., RCO 1 had to ask where the HVAM suction was located and had to ask if they were okay in the vestibule).

Analysis

Personnel participating in the Radiological Worker II qualification program are trained that dosimeters, security badges and Radiological Qualification Badges should be worn under the innermost set of protective clothing. The observed practices of removing the items from inside protective clothing as well as donning hoods and respirators after entering a posted CA are contrary to prudent contamination control techniques, and increase the likelihood of contaminating the exposed items or portions of the body. Poor protective clothing removal techniques, while not having significant impact on the accident, demonstrated a lack of respect for the steps utilized during removal to minimize the spread of contamination. Radiological control personnel are not only responsible for their own performance, but also monitor adherence to the site-specific radiological control manual and assist and guide workers in the radiological aspects of work.

2.2.7 Documentation of Safeguards and Security Requirements

Facts

- The WSRC operations crew performing work during the accident was unclear as to MC&A requirements under abnormal conditions.
- FB-Line procedures did not include guidance on MC&A requirements under abnormal conditions.
- The WSI-SRS Post Order for Vault Openings did not provide guidance on implementing contingencies relating to facility-specific safeguards and security requirements under abnormal conditions.

Analysis

Due to the lack of written guidance, OPS 1 was unclear about MC&A requirements under abnormal conditions. As a result, OPS 1 re-entered an airborne contamination environment. WSRC's MC&A Plan (WSRC-IM-92-041, Rev. 2) identified safeguards and security requirements applicable to emergency evacuations. The Plan directed facilities to define procedures and actions to be taken following an emergency evacuation, and defined minimum requirements to be included in the facility-specific procedures. In accordance with WSRC 14Q, *Material Control and Accountability, Special Physical Inventories*, the Material Balance Area Custodian is to establish procedures for conducting special inventories, which may result from circumstances including an abnormal occurrence or emergency facility evacuation. The MC&A Manager is to determine and document the scope of special inventories. The Board found that the guidance from the WSRC MC&A Plan and WSRC 14Q with respect to abnormal conditions had not been documented in FB-Line procedures as required. WSRC operators performing routine work in FB-Line lacked written safeguards and security procedural guidance to conduct job tasks.

The WSI-SRS Post Order for Vault Openings directed the zone lieutenant to resolve problems, but did not provide direction on abnormal conditions. Concerns such as supervisory interface with WSRC, alternate evacuation procedures from the affected area, preventing cross-contamination between workers in the affected area and security police officers in the exit path, and security police officer compliance with RWPs were not addressed.

2.3 MANAGEMENT SYSTEMS ANALYSIS

WSRC's FB-Line responsibilities include managing the FB-Line facility and operating processes, providing radiological controls, ensuring safety and health, and controlling and accounting for special nuclear materials (i.e., MC&A). WSI-SRS provides total security support services for SRS, including access control, property protection, and alarm equipment monitoring. DOE administers and oversees both the WSRC and WSI-SRS contracts.

2.3.1 WSRC Management Oversight

The FB-Line Facility Manager is responsible for facility operations. The Manager reports to the F-Area Operations Manager, then to the Vice President for Nuclear Materials Stabilization and Storage. The FB-Line Facility Manager is supported by the FB-Line Operations Manager, an FB-Line Facility Support Manager, and a Maintenance/Construction Support and Work Center Manager. In addition, he has a deputy, a Radiological Improvements/ALARA Coordinator, and an RCO Facility Manager (provided through matrix support).

Facts

- The WSRC Vice President responsible for FB-Line initiated an assessment of radiological practices in FB-Line on October 14, 1999. The assessment was headed by the F-Area Operations Manager. The WSRC team's documented observations, dated October 25, 1999, included the following: A CA was down-posted without recording the radiological survey data required to justify the action. Also, two personnel exited a CA, one of several CAs in the local area, without doffing personnel protective clothing (no spread of contamination occurred). After improperly exiting the first CA, the personnel entered another CA. The personnel did doff protective clothing properly after exiting the second area. Finally, the WSRC team noted that a heightened sensitivity to radiological work practice compliance following the September 1 accident was not apparent.
- 1997 and 1998 external evaluations conducted by the WSRC Facility Evaluation Board documented findings similar to those found during this investigation. The July 1997 report found radiological controls "below average." Need for improvement was identified in contamination control practices, internal exposure control, and external exposure tracking. The August 1998 report also identified radiological controls as "below average." The report states, "There is a continuing need for improvement in Radiological Controls." The report continues, "Performance and programmatic improvements were needed in many areas." Weaknesses were identified in several programmatic areas, including contamination control, containment integrity, exposure control, air monitoring, and the overall conduct of radiological operations.
- During the past year, DOE-SR Facility Representatives had performed relevant assessments of FB-Line, with observations including "a lax attitude toward common radcon practices noted in the vault/vestibule" and personnel donning outer protective clothing and a respirator in a CA. A report from September 23, 1997, noted less than adequate conduct of radiological operations practices as well as very minimal airflow between the vault and the vestibule.

- In July 1997, WSRC completed an analysis of the DOE's Type B Accident Investigation Board *Report of the Plutonium Intake, Between August 4, 1996-February 10, 1997, by a Crane Operator at Savannah River Site F-Canyon.* Issues cited in the F-Canyon report include inadequate characterization of radiological conditions, inadequate RWPs, inadequate pre-job briefs, and failure to ensure verbatim compliance with procedures.
- The most recent Integrated Management Evaluation for FB-Line was issued in December 1997. A draft evaluation was issued in March 1999, and included data from July 1997 through December 1998. WSRC Assessment Manual 12Q, Procedure ME-1, requires annual management evaluations.
- The draft Annual Management Evaluation, dated March 25, 1999, identified potential significant issues relevant to this accident: "Management had not maximized the Self-Assessment program as a tool for continuous improvement, with many assessments behind schedule;" "During completion of the bagless transfer project, several deficiencies were identified that indicated lack of readiness: "RCO and radiation workers knowledge and adherence to radiation protection practices, including attention to detail, were lacking which contributed to overexposures" and "Conduct of Operations breakdowns, resulting from inattention to detail and failure to follow procedures, were identified."
- A Readiness Assessment by FB-Line management was completed prior to the start-up of the bagless transfer system. The scope included a review of the safety envelope, safety systems, special processes (welding), and personnel qualifications. Based on DOE validation team input, DOE stated, "In the first few days of the DOE Readiness Assessment, it became evident that the facility performed an inadequate evaluation of their [WSRC FB-Line Operations] readiness." (Ref. Attachment to letter, Watkins to Jordan, August 27, 1997.) A demonstration run was suspended for one week until the facility demonstrated that the deficiencies identified by the DOE validation team had been satisfied.
- WSRC senior management stated they have made a significant effort to improve radiological control in FB-Line, and an annual Radiological Improvement Plan has been written to ensure continued improvement. A primary focus of the Plan is to rollback CAs within the facility. Management stated that success has been achieved in reducing the controlled CAs within the FB-Line and frequently cited the reduction in the numbers of personnel contamination cases in 1999, prior to the accident.

Analysis

Each of the reviews identified in the facts above contained issues and findings relevant to this accident. Indicators of existing problems were available to management for a considerable period of time prior to the accident, and should have enabled them to implement effective corrective actions and to validate their effectiveness. The most obvious correlation is with the findings of the F-Canyon accident investigation. As shown in Table 2-3, several causal factors identified in that accident report are similar to concerns identified during this investigation. Because these are contiguous facilities managed by the same senior managers, the F-Canyon accident should have provided many important lessons learned for FB-Line. Equivalent statements can be made for the results of other reviews: the 1997 Facilities Evaluation Board (FEB) Report, in which below average radiological control practices were noted in contamination control, internal exposure control, and external exposure tracking; the 1998 FEB Report, in which weaknesses were cited in contamination control, containment integrity, exposure control, air monitoring, and overall conduct of radiological operations; and the draft Annual Management Evaluation, dated March 25, 1999, in which self-assessment , adherence to radiological practices and failure to follow procedures were among areas identified. Other references include Facility Representative tour reports and the FB-Line Readiness Assessment written by DOE-SR. It is important to note that some of the reviews identified during this investigation discuss issues that predate the accident by 3 years. As noted in the facts in Section 2.2.4 in this report, there are indicators that can be traced back to 1994.

Table 2-3. Related F-Canyon Accident Causal Factors

F-Canyon Accident Causal Factor	FB-Line Accident
Failure to adequately characterize workplace radiological conditions.	Failure to take dose rates at vault door. Failure to survey racks upon initial entry. Failure to survey cans before they were handled.
Failure to properly post and control radiological boundaries.	Boundary between ARA and CA was not marked.
Inadequate job planning/work package preparation/pre-job briefs/ALARA reviews.	Procedure addressing pre-job brief not followed. WSI-SRS security police officers did not attend brief.
Failure to ensure verbatim compliance with procedures.	See "Procedural Compliance" in Section 2.2.5.
Inadequate specification of who was in charge of the job.	No one in the vault/vestibule was designated as in charge for the September 1 work.
Failure to perform adequate Job Hazard Analyses.	See "Job Hazard Analyses" in Section 2.2.5.
Inadequate management analyses of operating conditions.	Hazard analysis was not adequate to ensure worker safety during interim plutonium storage and handling. Radiological surveys were not performed to adequately characterize the work space conditions. Vault airflow was near stagnant, which subsequently put HVAM response in a less than optimum configuration. Potential failure of containers in the vault had not been analyzed to protect the workers in the vault/vestibule areas.

2.3.2 DOE Oversight

DOE provides oversight of FB-Line operations through an organization responsible to the Assistant Manager for Material and Facility Stabilization (AMMFS). The Assistant Manager has assigned a senior facility representative and two facility representatives to FB-Line, with offices in the facility. AMMFS includes a Nuclear Materials Engineering Division, providing specialty technical assistance to facility representatives and maintaining FB-Line safety basis documents. The Assistant Manager has access to additional technical assistance through the Assistant Manager for Health, Safety and Technical Support.

Facts

- A review of the E3S Exit/Entry Log for July and August 1999 indicated that facility representatives were the only AMMFS staff to enter the FB-Line processing areas. AMMFS engineering group employees stated during interviews that their workgroup was heavily burdened reviewing safety basis documents and unreviewed safety questions. Senior management stated during interviews that they would like to spend more time in FB-Line, but were unable to because they were responsible for numerous facilities. The radiological protection specialist providing matrix support stated during an interview that recently, his time in the facility had been very limited because of the wide scope of his responsibilities.

- Facility representatives have a very rigorously formatted assessment program, in accordance with SRIP 430.1, *Facility Representative Program.* During the past year, they had performed relevant assessments of FB-Line, with observations including "a lax attitude toward common radcon practices noted in the vault/vestibule" and personnel donning outer protective clothing and a respirator in a CA. A report from September 23, 1997, noted less than adequate conduct of radiological operations practices as well as very minimal airflow between the vault and the vestibule.
- During interviews, AMMFS senior management (including the acting Division Director for Nuclear Material Engineering) did not refer the Board to any technical assessments that might be relevant to the accident.
- The AMMFS Annual Assessment Plan scheduled one Engineering Division assessment for FB-Line in 1999, "FB-Line Material Characterization." This assessment was completed in June 1999, and focused on criticality safety of FB-Line Material Characterization Operations and related safety documents. Additional 1999 FB-Line technical assessments addressed backup power testing and fire protection. No 1999 technical assessments contained observations or findings relevant to this accident.
- Two AMMFS management (defined for this purpose as GS-14 technical staff and above) walkthroughs were documented for FB-Line for calendar year 1999 at the time of this investigation. Three were completed in 1998. The primary focus of documented walkthroughs was housekeeping, and none resulted in any required corrective actions.
- DOE-SR validated the FB-Line corrective actions that resulted from the F-Canyon event.
- The award fee evaluation for WSRC performance during Period 5 (October 1, 1998, through March 30, 1999) identified the following deficiencies applicable to all AMMFS facilities, which include FB-Line: "(1) inattention to detail and procedural compliance issues continued to occur affecting Conduct of Operations – further improvement is needed; [and] (2) further improvement in radiological control practices is required...".

<u>Analysis</u>

DOE-SR was presented with many opportunities to correct problems resulting in this accident over a long period of time prior to it. For example, the performance of WSRC during the readiness assessment for start-up of FB-Line bagless transfer operations was a strong indicator of the inability of WSRC management and staff operating the FB-Line to be self-critical and to understand their own state of readiness. Many other examples exist as indicated in the facts in this section and Section 2.3.1 of this report.

2.3.3 WSI-SRS Management Oversight

WSRC and WSI-SRS have established an Interface Protocol Document pursuant to the authority and the direction of DOE-SR and subject to terms of their contracts. Under this document, WSRC responsibilities include directing all operational emergency response operations, maintaining custodianship and operation of all emergency response organization facilities, performing emergency planning in conjunction with WSI-SRS, and preparing and maintaining operating contractor emergency plans and procedures. WSI-SRS provides security protection and law enforcement services. Specific WSI-SRS duties and interfaces with respect to emergency events include providing security during area evacuations and other emergency procedures; directing security emergency response operations; and participating in the emergency response training, drill, and exercise program in support of overall site emergency response.

Fact

- Based on interviews and documentation, WSI-SRS does not participate in facility operational drills and exercises.

Analysis

The Board evaluated WSI-SRS management oversight with regard to the WSI-SRS/WSRC interface. In accordance with WSRC 2S Procedure 3.3, *Conduct of Operations-Facility Drills and Monitored Evolutions*, WSRC is responsible for coordinating emergency drills and exercises with other facilities and organizations that may be required to respond or provide resources to an area/facility drill or exercise. WSRC was responsible for coordinating with WSI-SRS on area/facility-specific evacuation and/or sheltering drills. WSI-SRS played a major role in providing security for these drills, and WSRC coordinated with WSI-SRS when access control or response could impact a drill or exercise. WSRC provided WSI-SRS a monthly schedule of site-wide drills and exercises, identifying the degree of participation organizations other than WSRC were requested to provide. WSI-SRS attended pre-planning meetings based on their identified level of participation.

The Board found little interaction between the two with regard to facility-specific drills other than fire drills and Nuclear Incident Monitor alarm activation drills. WSRC and WSI-SRS had adequate interfaces with respect to Emergency Preparedness drills and exercises. However, adequate interface did not exist with regard to Conduct of Operations and radiological drills even though in many cases, these drills impacted the WSI-SRS mission. WSI-SRS security police officers are stationed throughout the facility and could be affected by adverse radiological conditions or events in the facility at any time, but were not included in the drills.

2.4 BARRIER ANALYSIS

Barrier analysis is based on the premise that hazards are associated with all accidents. A barrier is any means used to control, prevent, or impede the hazard from reaching the target (persons or objects that a hazard may damage, injure, or harm). Table 2-4 presents the Board's summary of physical and management barriers, consolidated from Table 2-5. Table 2-5 documents the complete barrier analysis performed by the Board.

Table 2-4. Consolidated Barrier Analysis and ISMS Link

TARGET →	Worker
Physical Barriers →	1. Respiratory Protection 2. Bagless Can Weld 3. Ventilation System
Management Barriers →	4. Radiological Work Practices 5. Radiological Surveys 6. Command & Control/Communication 7. HVAM Alarm Response 8. Job Hazards Analysis 9. Pre-Job Brief 10. Verbatim Compliance with Procedures 11. WSRC/WSI-SRS Drill Interface 12. Quality Assurance-Weld Inspection on Bagless Can 13. WSI-SRS Post Order 14. Vault Entry/Exit Procedure 15. Constant Air Monitoring 16. Technical Basis
HAZARD →	Breathing Airborne Contamination

The identified physical and administrative/managerial barriers link to the five core **Integrated Safety Management System functions** as follows:

- Define Work Scope: 3, 9, 13, 14.
- Analyze Hazards: 5, 8, 7, 16.
- Implement Hazard Controls: 1, 2, 3, 5.
- Perform work Within Controls: 3, 4, 5, 6, 7, 10, 15.
- Provide Feedback for Improvement: 11, 12.

Table 2-5. Barrier Analysis

What Was the Barrier?	How Did the Barrier Perform?	Why Did the Barrier Fail?	How Did the Barrier Affect the Event?
Personal Protective Equipment	Respiratory protection not used by all personnel. Respirator seemed to perform as expected, but some contamination found on the inside of the mask.	Not all personnel required to wear respiratory protection--RWP required only personnel entering vault to wear masks. Respirator taken off in vestibule after operator returned from second entry into vault. Conditions exceeded respirator's protection factor.	All personnel not protected from airborne contamination. Respirator did prevent even greater inhalation intake by operator.
Bagless Can Weld	Weld failed.	Inadequate Quality Assurance Program. Weld failure not detected.	Personnel contamination occurred.
Ventilation System	Near stagnant airflow in vestibule and vault.	Airflow from vestibule to vault insufficient to ensure contamination not spread from vault to vestibule.	Contamination source at vault/vestibule door caused vestibule airborne contamination.
CAM	Should have been used in vestibule but was not.	CAM not required in vestibule per FB-Line procedure/RWP.	Personnel not aware of vestibule airborne radioactivity in a timely manner.
RWP	Requirements not followed verbatim.	RCO did not perform all specified surveys. Two operators failed to sign-in on RWP. One performed hands-on task indicating he did not understand RWP requirements.	Inadequate surveys created missed opportunity to identify high levels of contamination on can. No direct effect from lack of operator sign-in.
RCO Air Monitoring Alarm Procedure	Procedure not followed.	RCO did not survey OPS 1 upon OPS 1's exit from vault. OPS 1 re-entered vault without RCO knowledge and concurrence.	Contamination spread in vestibule. Additional exposure to airborne radioactivity occurred.
Radiological Posting Procedure	Procedure not followed.	Boundaries not used at vault/vestibule transition.	Affected can set in vestibule prior to survey.
Contamination Surveys	Proper surveys not performed.	RCO did not perform complete surveys as required to adequately characterize the work site. RCO did not swipe can before it was handled and did not fully characterize can contamination before decontamination.	Missed opportunity to identify high contamination levels and take appropriate action.
Personnel Surveys	Several personnel surveyed multiple times before contamination was detected.	Poor survey techniques.	External contamination undetected for several hours, creating potential for additional spread.

What Was the Barrier?	How Did the Barrier Perform?	Why Did the Barrier Fail?	How Did the Barrier Affect the Event?
Command and Control	Lack of supervision and guidance. Response to emergency/abnormal operation procedures failed to get workers out of area in a timely manner.	Differing priorities not clearly established (OPS/RCO versus material control).	Urgent need to evacuate area delayed by material control concerns.
Communications	Communications ineffective, exiting workers did not warn others along exit path of potential for contamination.	No one took charge, work groups did not coordinate. Lack of formal communication between operators and operations supervisor.	Other personnel not notified of potential for cross-contamination.
RCO Supervision	Eleven personnel processed through one decontamination facility.	Supervision did not make decision to utilize other available facilities.	Delay in identification of need to refer personnel to medical for chelation consultation.
HVAM Alarm	HVAM alarmed, but there was no assurance it was timely or provided a representative sample.	Air exchanges in room inadequate to allow proper operation of the HVAM.	Personnel may have remained in the area of airborne radioactivity for a longer period of time.
RWP Integration	RWP did not provide integrated evaluation of work environment, did not consider need to provide compensatory controls due to poor ventilation and heat, did not adequately address personal protective equipment needs.	RWP preparation did not adequately analyze all hazards.	Personnel not adequately prepared for hazards confronted during the accident.
Pre-Job Brief	Procedure addressing pre-job brief not followed. WSI-SRS security police officers did not attend.	Briefing did not address air monitor alarms. Work considered routine. WSI-SRS personnel not normally included in pre-job briefs for work considered routine.	Missed opportunity to review required actions in response to air monitor alarms. No direct affect from lack of WSI-SRS participation.
Verbatim Procedure Compliance	Numerous procedural violations, e.g., personnel did not follow SOP requiring supervisory notification if contamination found, did not notify supervision when RWP suspension guidelines were exceeded, did not notify WSI-SRS supervisor and Central Alarm Station as post orders required.	Poor conduct of operations.	Exacerbated accident consequences; compliance may have prevented accident.

What Was the Barrier?	How Did the Barrier Perform?	Why Did the Barrier Fail?	How Did the Barrier Affect the Event?
Drills	Workers responded poorly to actual air monitoring alarm.	Operations day crew and WSI-SRS not drilled on radiological events. Operations First Line Supervisor had little drill experience as supervisor.	Crew remained in area longer than necessary after alarm.
AOP for the CAM Alarm	Failed to detect contamination on worker exiting vault.	Worker not surveyed upon exiting vault as required by AOP.	Missed opportunity to detect contamination on worker prior to spread of contamination.
JHA	Did not identify all hazards associated with work.	Analysis not performed for specific work in context of actual work environment.	Integrated hazards not identified in advance of performing work.
Vault Opening Order	Did not address security consideration during abnormal conditions such as an HVAM alarm.	Inadequate consideration of all potential circumstances.	Would have provided contingency guidance to WSI-SRS security police officers.
Vault Entry/Exit Procedure	WSRC operators unsure of MC&A requirements.	Facility procedure did not provide adequate guidance for MC&A during abnormal conditions.	Would have provided MC&A guidance to WSRC operators.
WSRC/WSI-SRS Drills Interface	Interface Protocol Document between WSI-SRS and WSRC not taken to facility Conduct of Operations drill level.	Insufficient performance testing through joint facility-specific Conduct of Operations drills with regard to abnormal conditions.	Would have provided both WSRC and WSI-SRS an opportunity to implement contingencies relating to operations and security requirements during abnormal conditions.
Quality Assurance-Weld Inspection/Can	Weld defect was not detected.	Quality assurance program elements not sufficient to ensure weld failure was detected.	Personnel contamination occurred.
Site-specific Technical Basis for interim storage of plutonium-bearing materials.	Not performed.	Not performed.	Storage configuration not adequately analyzed.

2.5 CHANGE ANALYSIS

Change analysis examines planned or unplanned changes that caused undesirable outcomes. This technique analyzes the difference between what has occurred before or was expected, and the actual sequence of events. Change analysis was performed utilizing guidelines set forth in the DOE Workbook *Conducting Accident Investigations*, Rev. 2. A chronological change analysis was performed utilizing the Summary Events and Causal Factors Chart in Appendix B, and is presented in Table 2-6.

Table 2-6. Chronological Change Analysis

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference between Accident and Ideal	Effect on Accident
Can welded on 7/14/98 with defect	Can welded with no defect.	Can had defective weld.	Release path for plutonium outside can.
Can inspection did not identify weld defect.	Weld defect identified and can repackaged.	Did not identify weld defect.	Defect not identified by bagless transfer operations personnel.
Can with defect passed helium leak checks.	Defect detected by leak check.	Defect not detected.	Defect not identified by bagless transfer operations personnel.
Near stagnant airflow identified since 1994.	Vault had adequate air changes.	Vault had near stagnant air conditions.	HVAM operation less than adequate. Increased possibility of spreading contamination outside vault.
HVAM alarm response not discussed at pre-job briefing. WSI-SRS not present at pre-job.	Pre-job covered work, radiological conditions, abnormal events/response, emergency response, and safety.	Personnel not prepared for abnormal conditions.	Response to HVAM less than adequate.
RCO 1 performed contamination survey of vault floor.	10 CFR 835/WSRC 5Q require monitoring to detect changes in radiological conditions in the workplace.	Survey limited to floor, did not fully characterize the workplace.	Potential to identify abnormal radiological conditions in areas other than the floor.
OPS 1 retrieved can without RCO survey of can.	RCO surveyed can prior to handling of can.	RCO did not survey can per RWP.	Potential to identify contamination on can prior to handling.
OPS 1 placed can on cloth in vestibule.	Surveyed can inside vault, read swipes at doorway.	Contamination source (can) brought into vestibule prior to survey.	Potential personnel exposure to plutonium.
RCO 1 swiped can, detected 2000 dpm alpha/100 cm^2, told OPS 1 to decontaminate can.	When RWP suspension guide limits exceeded (≥2000 dpm alpha/100 cm^2), stopped work, notified operations or RCO supervision.	Work not stopped, decontamination performed inside vault.	Potential personnel exposure to plutonium.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference between Accident and Ideal	Effect on Accident
Vault HVAM alarm received in vestibule and Precipitator Control Room at 1047 hours.	Crew proficient at response due to facility drills (WSRC/WSI-SRS).	Drills targeted at shifts, day crew and WSI-SRS do not conduct Conduct of Operations drills together (not integrated).	Alarm response less than adequate.
OPS 1 exited vault without being surveyed per procedures and closed vault door.	OPS 1 surveyed in accordance with procedures. Vault door closed to reduce potential exposure to airborne contamination.	OPS 1 not surveyed.	Potential to spread contamination and personnel exposure to plutonium.
OPS discussed re-entry into vault to secure can (MC&A focus), called First Line Supervisor for assistance.	Procedures address MC&A under abnormal conditions. Supervisor knowledgeable of procedural requirements. RCO permission (First Line Supervisor) requested for vault re-entry (communication). WSI-SRS post orders contain abnormal condition response requirements.	Procedures did not address MC&A requirements under abnormal conditions. First Line Supervisor not knowledgeable of MC&A requirements. No communication between OPS, RCO, WSI-SRS. WSI-SRS post orders did not contain response requirements for abnormal conditions.	Confusion on how to respond with regard to safety versus security. First Line Supervisor knowledge less than adequate. Communication between all parties less than adequate. WSI-SRS post orders less than adequate.
OPS decided to re-enter vault and secure can.	Re-entry not required by MC&A requirements. Vault secured.	OPS re-entered vault and secured can.	Additional personnel exposure to plutonium. Increased potential to expose personnel in vestibule upon OPS 1's exit from vault.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference between Accident and Ideal	Effect on Accident
RCO responded to HVAM alarm	Ideally ≤5 minutes to make decision with near stagnant flow and existing HVAM: • Survey OPS 1 (2-3 min.) • Read/pull HVAM planchet (1 min.) • Monitor filter paper in vestibule (1 min.) • Exit area.	RCO did not survey OPS 1. Approximately 18-19 minutes spent in vestibule after HVAM alarmed.	Potential spread of contamination into vestibule. Increased exposure time to potential contamination.
Personnel exit vestibule together to third level.	Crash out and inform Central Alarm Station. Exit in orderly fashion. Inform OPS 6 of potential contamination event WSRC and WSI First Line Supervisors coordinate exit through third level (including security requirements for exiting vault and re-entering FB-Line).	Personnel did not crash out. Seven people entered/exited security doors. OPS 6 not informed of contamination event. WSRC/WSI First Line Supervisors did not coordinate exit of eight personnel	Potential cross-contamination of personnel.
Site-specific Technical Basis for interim storage of plutonium-bearing materials.	Site-specific technical basis developed.	Site-specific technical basis not developed.	Preparation of site-specific technical basis could have resulted in use of double containment or appropriate technical justification/quality assurance for single containment.

2.6 INTEGRATED SAFETY MANAGEMENT SYSTEM ANALYSIS

Safety management activities are grouped into five core integrated functions: (1) define the scope of work, (2) identify and analyze the hazards associated with the work, (3) develop and implement hazard controls, (4) perform work safely within the controls, and (5) provide feedback on adequacy of the controls and continuous improvement in defining, planning, and performing work. These five functions provide the necessary structure for any work activity that could potentially affect the worker, public, or the environment. The formality and rigor needed to address each function varies based on the hazards involved with the work. The Board analyzed the relationship between the causal factors and findings disclosed during this investigation and the five core integrated safety management functions.

Define the Scope of Work

Modifications to correct the deficient ventilation system had not been included in the authorized work scope for several years, even though the inadequacy of the vestibule and vault ventilation system had been known to be a problem since 1994. Near stagnant ventilation conditions in the vestibule significantly contributed to the radiological conditions that resulted in the intake. A supply air modification had recently been initiated and was ongoing at the time of the event.

WSRC supervision did not adequately define the work scope in RCO procedures for handling radiological contamination cases and suspected intakes of radioactive material. RCO supervision did not properly define and distribute the workload for the eleven actual and potentially contaminated people at the 221-F-Canyon monitoring and decontamination station. The 221-F station was overburdened by the number of people requiring processing, yet other personnel decontamination stations in F-Area were not utilized. This delayed identification of the need to refer personnel to medical for chelation consultation.

The Pre-Job Briefing conducted for the material handling evolution did not include all work groups participating in the evolution, and did not address the required response for foreseeable contingencies. WSI-SRS security police officers did not attend the pre-job briefing. Discussion of required actions on a high airborne condition were not discussed, despite being a required item on the pre-job briefing checklist. MC&A requirements were not contained in the facility vault entry/exit procedure and were not addressed with the work group during the pre-job briefing. Lack of understanding of MC&A requirements by the operations staff drove them to the unnecessary re-entry into the vault to secure material.

The scope of WSI-SRS Orders did not address actions on abnormal conditions such as a HVAM alarm during material handling activities. This contributed to confusion and misunderstanding between operations and security on what should be done to secure the vault.

Identify and Analyze Hazards

FB-Line JHAs for material handling do not provide an integrated assessment of the work activity in the environment in which it is performed. A JHA was not performed for the work being performed in the vault on September 1, but a JHA performed on a similar material packaging job was stated to represent the anticipated hazards for this evolution. This JHA considered only common industrial hazards (such as foot injury, hand/finger injury, and back strain), and addressed potential heat stress by having applicable guidelines addressed in the pre-job briefing for current facility conditions. The JHA did not address the combination of hazards (i.e., the unpacking evolution in a hot environment in a CA/HRA/ARA) encountered in performing the work. The JHA did not address all these concerns in an integrated manner incorporating the various work groups involved. The WSRC site guidance document for the JHA program effective on September 1 (revised on September 24, 1999) contributed to this lack of integration.

It provided for performing evaluations to enhance safety aspects of tasks/procedures not evaluated by existing processes (including Work Clearance Permits and RWPs).

The FB-Line Safety Analysis report identifies a pressurization/overpressure event that could cause release of plutonium outside normal confinement as a credible event. This postulated event was not analyzed for worker protection for personnel working in the vault.

DOE promulgated criteria for interim storage of plutonium that included a requirement for two contamination barriers. Each site was required to prepare a technical basis addressing the criteria. A site-specific technical basis for plutonium storage in FB-Line was not prepared to address compliance with the criteria, including the guidance that double confinement for storage of plutonium be provided.

Radiological surveys performed prior to beginning material handling activities were inadequate to characterize the work area. Surveys for contamination on the storage racks to establish contamination levels in the planned work area were not required by the RWP. All radiation and contamination surveys required by the RWP were not performed. The radiation dose rate at the vault entrance was not established prior to entry. The contamination level on individual containers was not determined before the containers were handled and removed from their storage location, as required by the RWP.

The HVAM was relied upon to sample the vault atmosphere and provide timely warning of unfavorable conditions. Due to the minimal airflow conditions prevalent in the vestibule and vault, air exchanges in the room were inadequate to allow proper operation of the HVAM. Thus there is no assurance that the HVAM provided a representative sample and/or timely warning.

Develop and Implement Hazard Controls

Ventilation system design was relied upon to provide airflow from the vestibule into the vault and thus prevent potential airborne activity in the vault from reaching the vestibule. However, airflow in the vestibule and vault was near stagnant, a condition known to management since at least 1994. Little or no action was taken to compensate for the lack of ventilation, as different levels of personnel protection were specified for people in the vault and vestibule based on activity in the vault not reaching the vestibule due to airflow into the vault. The limited effectiveness of this control was also invalidated when the contamination source was brought into the vestibule. A design modification to provide supply air and improve the airflow in the rooms had been initiated and was ongoing at the time of the accident.

Real-time air monitoring using continuous air monitors is required in areas where an individual is likely to be exposed or where there is a need to alert potentially exposed individuals to unexpected increases in airborne radioactivity levels. Given the known stagnant airflow conditions, real-time air monitoring should have been performed in the vestibule, which is in constant communication with the vault (posted ARA) during material handling activities.

The RWP and RCO Posting procedures provided the administrative hazard controls for the work and location. The RWP specified that contamination surveys of the canisters be performed prior to handling. This survey could have detected the contamination prior to the can being moved into the vestibule. This required survey was not performed, a practice that was found to be widespread and longstanding. The RWP Suspension Guide Limit for work in the CA (vestibule location where the canister was located when initially swiped) was ≥ 2000 dpm alpha/100 cm^2. When 2000 dpm alpha/100 cm^2 contamination was found on the can, decontamination was begun in the vault without suspending work and notifying RCO Supervision. Thus, the RWP's administrative controls were violated and therefore ineffective. Site radiological procedures require that boundaries between areas of differing radiological conditions be clearly posted. There was no demarcation of the boundary between the ARA in the vault and the non-ARA in the vestibule. A clearly visible boundary could have discouraged the workers from moving the canisters into the vestibule before being characterized. Requirements for administrative hazard controls established for worker protection were violated and were thus ineffective.

The primary hazard control relied upon to protect workers from the plutonium hazard was the integrity of the welded bagless canisters. Post-manufacturing inspections and leak checks, and the canister surveillance program, failed to detect a flaw in one of the canisters, rendering the primary barrier ineffective. Given the failed canister, personnel protective equipment was inadequate to protect personnel. The RWP required personnel entering the vault to wear a respirator, while respiratory protection was not required for personnel in the vestibule. Personnel who entered the vault used a respirator to protect against the potential for airborne activity. This was required due to legacy contamination from previous events, not as protection from a potential leaking can. While this barrier provided some protection to the individual in the vault at the time of the alarm, the other six individuals in the vestibule were exposed to airborne contamination while not wearing respirators. After exiting the vault upon receipt of the HVAM alarm, the individual wearing a respirator re-entered an uncharacterized airborne area in the vault that exceeded the protection factor of the respirator. Respiratory protection was thus ineffective in controlling the hazard due to its limited and improper use.

Work Safely Within Controls

The Board determined that numerous instances of failure to comply with operating and response procedures and RWP requirements occurred. These procedures and requirements were designed as controls for the work and anticipated events. As previously stated, contamination and radiation surveys required by the Job-Specific RWP prior to beginning work were not performed. The response to air monitor alarms was not discussed at the pre-job briefing as required. The Shift Operations Manager and RCO First Line Supervisor were not informed when contamination was initially found on the canister as required by the material handling procedure that governed the work in progress. The contamination levels found on the can reached RWP suspension guidelines for work in a CA where the survey was performed, but work continued without informing supervision. The facility procedure for accessing HRAs that was required to be executed for the September 1 vault entry could not be located. The Board found that three identical procedures executed for similar entries the previous day were improperly completed. Key steps had not been signed off, but the procedures had been reviewed by supervision and signed as complete.

Requirements of RCO and Operations procedures for responding to air monitor alarms were not followed during the event. These procedures require that after evacuation of the affected area, RCO should immediately begin personnel surveys to determine if personnel in the affected area received personnel contamination or an assimilation. The operator in the vault at the time of the HVAM alarm was not surveyed upon exit from the vault. RCO procedures and Radiation Worker II training require that after an air monitor alarm, RCO Supervision shall approve re-entry into the affected area. The operator re-entered the vault after initially responding to the HVAM alarm without notifying or gaining permission from RCO. WSI-SRS security police officers aware of the alarm condition did not follow procedures to notify supervision and other security police officers. These procedure provisions, if performed as intended, could have lessened the consequences of the accident.

The Board determined that inadequate command and control significantly contributed to work and event response not being performed within established controls. WSRC procedures require that Shift Operations Managers maintain overall authority and responsibility for the direction and control of all activities within the facility, maintain awareness of the facility status, and ensure that the facility is operated in accordance with approved procedures. Formal communications were not established and maintained during the material handling evolution, and thus were limited following the HVAM alarm. The Operations First Line Supervisor responsible for the work in the vault did not supervise the evolution and did not keep abreast of job status as it progressed. He relied on the operators in the work area to execute the material handling activities. The First Line Supervisor was located on the third level, rather than the work site, and did not maintain direct communications with the workers in the vestibule. None of the seven workers at the event scene was designated as in charge during the planned activities, and no one took charge when the event occurred. Operations Supervision did not exercise its command and control responsibilities to confirm that workers carried out the requirements of the air monitor alarm response procedure. The First Line Supervisor relied on the training of the workers to ensure they knew what to do and responded correctly.

Individual responsibility for working within controls by performing thorough personnel surveys following exit from the CA was inadequate. All seven people in the accident area monitored at the CA exit without detecting contamination, despite the fact that significant skin and clothing contamination was present. Follow-up surveys were slow to detect the contamination, contributing to an increased potential for spreading contamination throughout the facility.

Provide Feedback for Improvement

The facility drill program is an important means for reinforcing proper response to abnormal events and providing facility management with feedback on the proficiency of their personnel. To maximize effectiveness, the drill program should include all work groups likely to be affected by anticipated casualties. The FB-Line facility drill program did not include all facility operations personnel and did not include all work groups likely to be affected by an actual event. Day shift operations workers were not routinely targeted by the operations drill program. Operations personnel involved in the event did not routinely participate in facility radiological drills. WSI-SRS security police officers could be affected by adverse radiological conditions or events in the facility at any time, but had not been included as participants in radiological control drills. Integrated operational drills that included all potentially affected work groups could have increased the state of readiness of the involved workers and provided feedback to management regarding weak areas in need of increased attention.

Quality Assurance is another method of providing feedback on the adequacy of completed work. Insufficient quality assurance controls were applied to the manufacture of the canisters, allowing a defective can to be produced and stored without being detected. The undetected flaw in the canister led directly to the accident.

Management issues identified in prior external reviews and self-assessments closely parallel causal factors identified in this investigation. The lessons learned from the 1997 F-Canyon accident investigation are very similar to those identified for this accident, and should have provided important lessons learned for FB-Line, particularly because the facilities are contiguous and are managed by the same senior managers.

The Board concluded that integrated safety management was not properly demonstrated during the planning and execution of the material handling activities and during response to the resulting event.

2.7 CAUSAL FACTORS ANALYSIS

Causal factor analysis was performed in accordance with DOE's Workbook, *Conducting Accident Investigations,* Rev. 2. Causal factors are the events and conditions that produced or contributed to the accident. There are three types of causal factors: direct, root, and contributing.

The direct cause is the immediate event or condition causing the accident. The Board determined the direct cause of the accident was the release of plutonium from a defective bagless transfer can that resulted in inhalation by FB-Line workers.

Root causes are factors that, if corrected, would prevent recurrence of the same or similar accidents. The Board identified the following root causes of the September 1 accident:

- Quality assurance on the bagless transfer canister was not adequate to identify the weld defect.
- Implementation of integrated safety management for plutonium vault operations was inadequate to provide worker protection during interim plutonium storage and handling.

The Board also identified contributing causes (events or conditions that collectively with other causes increased the likelihood of the accident, but individually did not cause it). A summary of the Board's causal factor analysis is presented in Table 2-7.

Table 2-7. Causal Factor Analysis Summary

Causal Factors	Discussion
Root Causes	
Quality assurance on the bagless transfer system canister was not adequate to identify the weld defect.	Weld integrity checks performed on the canister included both visual inspection and leak tests. The quality assurance performed on the bagless can did not identify the weld defect present in the can. SRTC's analysis of the failed can determined that the weld defect was present when the weld checks were performed.
Implementation of integrated safety management for plutonium vault operations was inadequate to provide worker protection during interim plutonium storage and handling.	Breakdowns occurred in all core functions of ISMS for vault activities, most significantly in the functions of Hazard Analysis, Develop and Implement Hazard Controls, and Feedback/Improvement. A Hazard Analysis for worker protection in the vault was not performed even though the Safety Analysis Report postulates a credible container pressurization/overpressure event that could release activity into the vault. The JHA applied to the material handling activity did not provide an integrated assessment of the work activity in the environment in which it was performed. DOE-SR did not prepare a technical basis for interim storage of plutonium-bearing materials. Radiological surveys of the vault prior to beginning material handling were not performed in accordance with the RWP and were inadequate to characterize the work area. Prior external reviews and the 1997 F-Canyon accident investigation identified many of the same weaknesses in performance that led to this accident, indicating weakness in WSRC and DOE-SR's feedback and improvement programs.

Causal Factors	Discussion
Contributing Causes	
Verbatim compliance with procedural requirements.	Evidence shows workers did not always perform work or respond in accordance with established procedures. For example, RCO did not survey the bagless can prior to handling, RCO did not fully characterize the vault radiological conditions, and RCO did not suspend work when contamination levels exceeded the suspension limits.
Vault/Vestibule ventilation system performance.	In normal configuration, the vault and the vestibule are essentially one room due to the near stagnant airflow in the vault. This condition, identified in 1994, increased the opportunity for spreading contamination inside the vestibule.
Vault HVAM alarm response.	Personnel response to a HVAM alarm was not discussed at the pre-job brief, and the affected personnel had not drilled in order to properly respond to an actual HVAM alarm.
Radiological work practices.	Examples of less than adequate practices include RCO failure to perform RWP required survey of items prior to handling, failure to completely characterize the radiological conditions of the work site, failure to completely survey the bagless can prior to initiation of the decontamination effort, failure to terminate the work when the suspension guide for the RWP was reached, failure to utilize radiological boundaries at the CA/ARA to CA transition, and inadequate survey techniques during survey of personnel.
Abnormal MC&A response.	There were no MC&A contingency requirements in the operations procedure on how to respond to an abnormal condition, such as a HVAM alarm. This led to confusion, added additional time in the vestibule (18-19 minutes total), and subsequently led OPS 1 to reenter the vault due to OPS 1 and OPS 3 perception of MC&A requirements. OPS 1 and OPS 3 stated that a total vault inventory would have to be performed if the can was not secured.
Security post orders.	Security post orders did not contain response requirements for abnormal conditions.
Pre-job briefs.	Pre-job briefs were being executed by the First Line Supervisor as a cursory type of briefing. Specific responses to alarms were not discussed with the personnel present.

Causal Factors	Discussion
Command & Control.	The First Line Supervisor did not supervise the work and did not keep abreast of job status. The First Line Supervisor was not present at the work site. Formal communications were not established and maintained during the work and subsequent alarm. The Operations First Line Supervisor did not exercise Command and Control to confirm that the requirements of the abnormal and alarm response procedures were being executed. Operations became concerned about the MC&A requirements for the vault while RCO was attempting to characterize the radiological conditions in the vault and vestibule. No one took charge during the alarm response and informed personnel of the proper response. This unnecessarily increased the time spent in the vestibule to 18-19 minutes total.
Vault HVAM operation.	Due to the lack of sufficient/recommended air changes, the vault HVAM did not provide timely and representative air sampling.

3.0 CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of the facts and results the Board considered particularly significant. Judgments of need are managerial controls and safety measures believed necessary to prevent or mitigate the probability or severity of a recurrence. They flow from the conclusions and causal factors, and are intended to guide managers in developing follow-up actions. The Board's conclusions and judgments of need are presented in Table 3-1.

Table 3-1. Conclusions and Judgments of Need

Conclusions	Judgments of Need
The bagless can was not subject to an adequate quality assurance program during production commensurate with its role as a primary barrier protecting the workers. Areas requiring particular emphasis include the visual inspection and the leak checks (gross and helium), both of which failed to detect the hole in the bagless can weld.	WSRC needs to define appropriate quality assurance controls for the bagless can, develop remedial measures for cans already produced, and evaluate whether remedial measures are necessary for all other types of containers in the vault. WSRC needs to provide qualified weld inspectors with appropriate training and equipment to enable an independent inspection of weld quality for bagless transfer system cans. WSRC needs to evaluate the operation, maintenance, and calibration of the leak detection system to ensure satisfactory weld failure detection.

Conclusions	Judgments of Need
WSRC management expectations regarding following procedures and work standards were not enforced for conduct of operations. For example, instances of non-compliance with operating procedures and RWPs occurred prior to and during the accident. Additionally, communications between workers during the event did not permit affected personnel to understand the nature of the event, and communications between affected workers and supervision did not result in adequate supervisory direction during the event. Pre-Job Briefings did not include comprehensive coverage of radiological contingencies.	WSRC management needs to communicate and enforce expectations regarding conduct of operations. WSRC needs to evaluate the required content of pre-job briefings and ensure that required topics are appropriately covered.
WSRC management expectations regarding following procedures and work standards were not enforced for radiological controls. For example, there was failure to perform an RWP-required survey of items prior to handling, failure to completely characterize work site radiological conditions, failure to completely survey failed can prior to initiation of decontamination, failure to terminate work when the RWP suspension guide limit was reached, failure to utilize radiological boundaries at the CA/ARA to CA transition, and failure to survey personnel exiting the vault following receipt of the HVAM alarm.	WSRC management needs to communicate and enforce expectations regarding conduct of radiological operations.
Command and Control during the material handling evolution and response to the HVAM alarm was inadequate.	WSRC management needs to ensure command and control concepts are understood and implemented by supervisory personnel.
The facility drill program did not include day crew operations and security group personnel likely to be affected by an actual event.	WSRC management needs to improve the facility drill program by including all organizations that could be impacted by actual facility events.
Issues identified for this accident are similar to those identified in the 1997 DOE Type B Accident Investigation report of a plutonium intake by a crane operator at the SRS F-Canyon. Similarities include failure to adequately characterize work site radiological conditions, inadequate job planning/work package preparation/pre-job briefs/ALARA reviews, failure to ensure verbatim compliance with procedures, inadequate specification of who was responsible for the job, failure to perform adequate JHAs, and inadequate management analysis of operating conditions.	WSRC management and DOE-SR line management need to (a) analyze implementation of lessons learned from the F-Canyon accident and develop corrective actions, (b) validate any corrective actions already implemented by FB-Line as a result of the F-Canyon accident, and (c) determine why corrective actions taken in response to the F-Canyon accident investigation report were not effective in mitigating the effects of this accident.

Conclusions	Judgments of Need
Due to lack of facility guidance, operations staff were unclear of Material Control and Accountability requirements during an abnormal event.	WSRC needs to include MC&A requirements during abnormal conditions in facility procedures and train affected personnel.
WSRC and WSI-SRS lack adequate interface during abnormal conditions.	WSRC and WSI-SRS need to develop a plan for improving communications and coordination between operations, Radiological Control Operations, and WSI-SRS during abnormal conditions.
Security post orders did not contain response requirements for abnormal conditions.	WSI-SRS needs to ensure security post orders contain response requirements for abnormal conditions.
WSRC and DOE-SR have been presented with many opportunities in the past to rectify problems identified either by them or others that resurfaced in this investigation and contributed to the accident.	WSRC and DOE-SR senior management need to determine the root causes of ineffectiveness in their feedback and improvement mechanisms and develop appropriate corrective action.
WSRC management did not adequately implement integrated safety management for plutonium vault operations.	WSRC senior management, independent of line management, needs to analyze why the breakdown in integrated safety management implementation for plutonium storage and handling activities occurred, and develop appropriate corrective actions. WSRC management needs to (a) analyze FB-Line vault/vestibule operations for worker protection and define appropriate controls, and (b) review other analyses for worker protection within FB-Line for adequacy and correct any identified deficiencies.
DOE-SR did not develop a site-specific technical basis document for interim storage of plutonium-bearing materials.	DOE-SR needs to develop a site-specific technical basis document for interim storage of plutonium-bearing materials.

4.0 BOARD SIGNATURES

Date: 2/8/00

Jeffrey M. Allison, Board Chairperson
U.S. Department of Energy
Savannah River Operations Office

Date: 2/8/00

Rowland Felt, Board Member
U.S. Department of Energy
EH-34

Date: 2/8/00

Larry Hinson, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 2/8/00

Charles E. Radford, CHP, RRPT, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 2/8/00

Steven T. Shelt, Board Member
U.S. Department of Energy
Savannah River Operations Office

Date: 2/8/00

Mark A. Smith, Board Member
DOE Accident Investigator
U.S. Department of Energy
Savannah River Operations Office

Date: 2/8/00

Edwin L. Wilmot, Board Member
U.S. Department of Energy
Savannah River Operations Office

5.0 BOARD MEMBERS, ADVISORS, AND STAFF

Chairperson	Jeffrey M. Allison, DOE Savannah River
Member	Rowland Felt, DOE EH-34
Member	Larry Hinson, DOE Savannah River
Member	Charles E. Radford, CHP, RRPT, DOE Savannah River
Member	Steven T. Shelt, DOE Savannah River
Member	Mark A. Smith, DOE Savannah River
Member	Edwin L. Wilmot, DOE Savannah River
Advisor	Michael J. Blackwood, WSRC
Advisor	P. Gary Eller, Los Alamos National Laboratory
Advisor	Ronald L. Kathren, CHP, DEE
Advisor	Victor Loczi, DOE DP-45
Advisor	David Sill, DOE Radiological and Environmental Sciences Laboratory
Accident Investigation Point-of-Contact	Fred Brown, DOE Savannah River
Technical Writer	Lauren Lovick, DOE Savannah River
Publisher	John Strack, WSRC
Administrative Support	Rylinda Felton, DOE Savannah River
	Alice Mercer, DOE Savannah River
	Dianne Powell, DOE Savannah River

APPENDIX A

TYPE B
ACCIDENT INVESTIGATION BOARD

APPOINTMENT
AND EXTENSION
MEMORANDA

DOE F ;5 8

United States Government — Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE: SEP 1 3 1999

REPLY TO
ATTN OF: MGR (G. Rudy, 5-2405)

SUBJECT: Type B Investigation – FB-Line Incident

TO: Distribution

I hereby establish a Type B Investigation Board to investigate the incident that occurred at the Savannah River Site's FB-Line on September 1, 1999. I have determined it meets the requirements established for a Type B accident investigation in DOE Order 225.1A, "Accident Investigations," Dated November 26, 1997.

I appoint Jeff Allison (Acting Assistant Manager for Health, Safety and Technical Support) as the accident board chairperson. The Board members will be:

- Ed Wilmot, Assistant Manager for National Security
- Mark Smith, Laboratory Operations Division
- Steve Shelt, Internal Security Division
- Chuck Radford, Radiation Protection Division
- Larry Hinson, High Level Waste Operations Division

Advisors, consultants and other support personnel as determined by the chairperson will assist the Board.

The scope of the Board's investigation will include, but is not limited to, identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the accident; developing conclusions; and determining the judgments of need that, when implemented, should prevent the recurrence of the accident. The investigation will be conducted in accordance with DOE Order 225.1A and will specifically address the role of DOE, contractor organizations, and management systems as they may have contributed to the accident. The scope will also include any deficiencies related to Integrated Safety Management System implementation and the application of lessons learned from similar accidents within DOE.

The Board will provide my office with periodic reports on the status of the investigation but will not include any conclusions until an analysis of all of the causal factors has been completed. Draft copies of the factual portion of the investigation report will be submitted to DOE and Westinghouse Savannah River Company for a factual accuracy review prior to report finalization.

2

SEP 1 3 1999

The report should be provided to me for acceptance by October 15, 1999 Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

Greg Rudy
Manager

MGR:FRM:dmy

cc: Carolyn Huntoon, EM-1
Glenn Podonsky, EH-2
J. J. Buggy, WSRC

SEP 1 3 1999

DISTRIBUTION:

Jeff Allison, Acting Assistant Manager for Health, Safety and Technical Support
Ed Wilmot, Assistant Manager for National Security
Steve Shelt, Internal Security Division, Office of Safeguards and Security
Chuck Radford, Radiation Protection Division, Assistant Manager for Health, Safety and Technical Support
Larry Hinson, High Level Waste Operations Division, Assistant Manager for High Level Waste

DOE F 1325 8

United States Government — Department of Energy (DOE)

memorandum

Savannah River Operations Office (SR)

DATE: OCT 1 2 1999

REPLY TO ATTN OF: AIB (J. M. Allison/803-952-4974)

SUBJECT: Extension of FB-Line Type B Accident Investigation Schedule

TO: Greg Rudy, Manager

Your memorandum of September 13, 1999, established the Type B Accident Investigation Board and requested that the investigation report be provided to you by October 15, 1999. To complete Part I of the report, I am requesting that the activities of the Accident Investigation Board be extended to November 5, 1999, based on the following facts.

The Type B Accident Investigation Board has been hampered by classification issues that have required "Q" cleared court reporters; Authorized Derivative Classifier/Reviewing Official review of all tapes and transcripts resulting from the interview process and development of a security plan for control of all information (tapes and transcripts) resulting from the interview process. These issues had never been faced in prior Accident Investigations, resulting in a slow start to the review process and making transcription of interview tapes a critical path activity. In addition, confirmation on September 27, 1999, that the bagless transfer canister was leaking through a weld failure led to a significant increase in the scope of the investigation. These conditions have caused the Board to take longer to identify relevant facts.

To date, the Board has not been able to positively identify the exact causal factors for the failure of the bagless transfer canister. The Board is actively following evaluation of the failed canister at the Savannah River Technology Center, and I recommend that a subteam of the Board continue to follow these activities through their completion in December 1999. At that time, the full Board would reconvene to finalize our report. Issuing Part I in November 1999 would ensure that the causal factors and lessons learned concerning the events of September 1, 1999, are disseminated and a corrective action plan developed by the facility.

Between now and submission of the report to you on November 5, 1999, the Board will perform the following activities:

- Perform analysis of facts, draw conclusions, casual factors and Judgement of Need's,
- Prepare a draft report,
- Allow the Assistant Manager for Materials and Facility Stabilization and the Nuclear Materials Stabilization and Storage Division to perform factual accuracy reviews,
- Allow the Office of Oversight (EH-2) to perform a review,

OCT 1 2 1999

Mr. Rudy -2-

- Brief you, the President of Westinghouse Savannah River Company, and the Office of Oversight on the report, and
- Issue the report to you, after the required classification and privacy act reviews.

I will issue a separate schedule to you for incorporation of the Board's analysis resulting from the facts gained from the testing of the failed bagless transfer canister.

Questions from you or your staff may be directed to me at (803) 952-4974.

Jeffrey M. Allison, Chairperson
DOE Type B Accident Investigation

AIB:JMA:rvf

cc:
C. Huntoon, (EM-1), HQ
D. Stadler, (EH-2), HQ
J. Buggy, WSRC

Approve: ____________

Disapprove: ____________

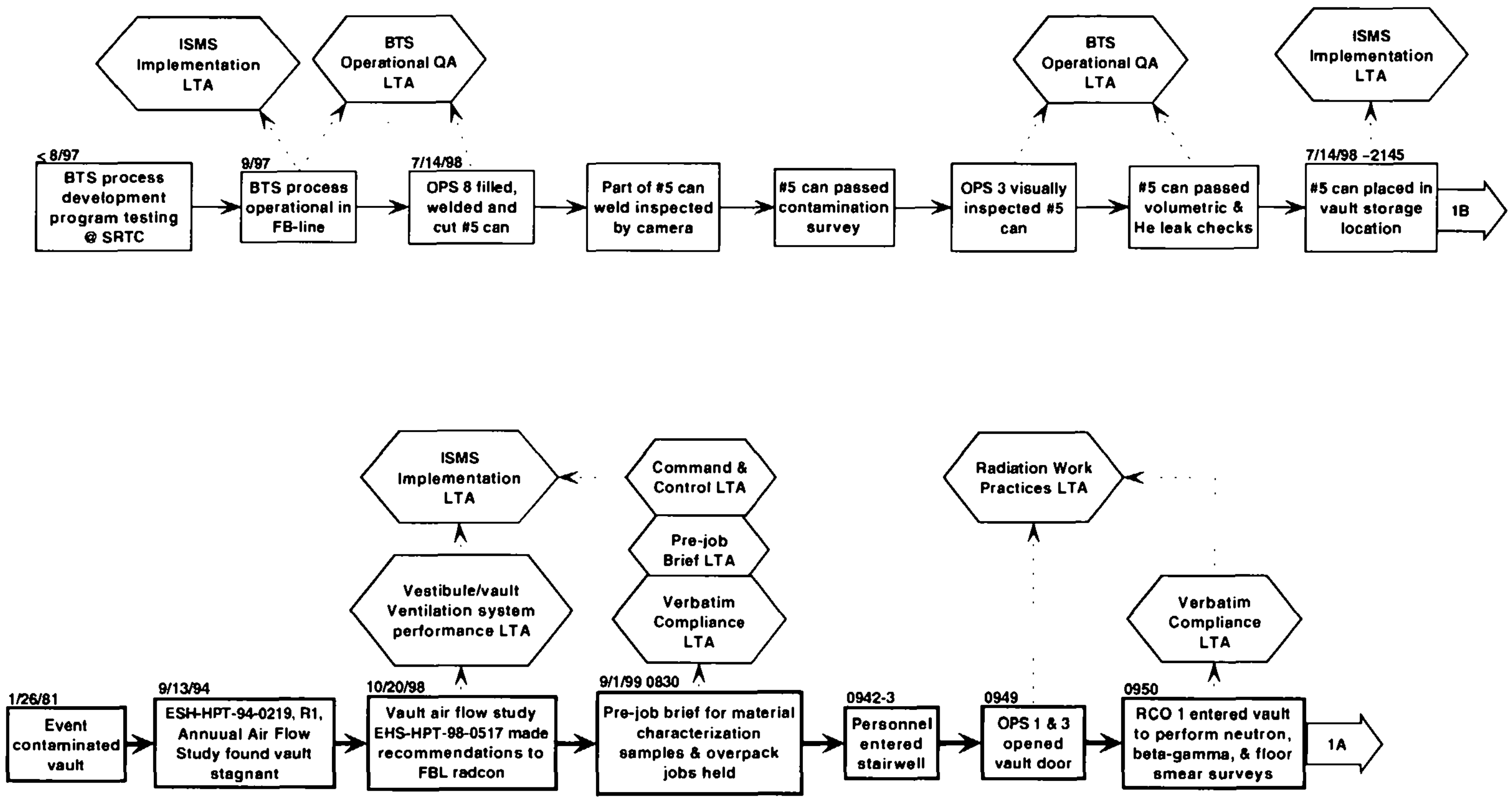
Date: ____________

APPENDIX B

SUMMARY EVENTS AND CAUSAL FACTORS CHART

Appendix B
Page 1 of 4

SUMMARY EVENTS & CAUSAL FACTORS CHART FOR PLUTONIUM INTAKES AT FB-LINE SEPTEMBER 1, 1999



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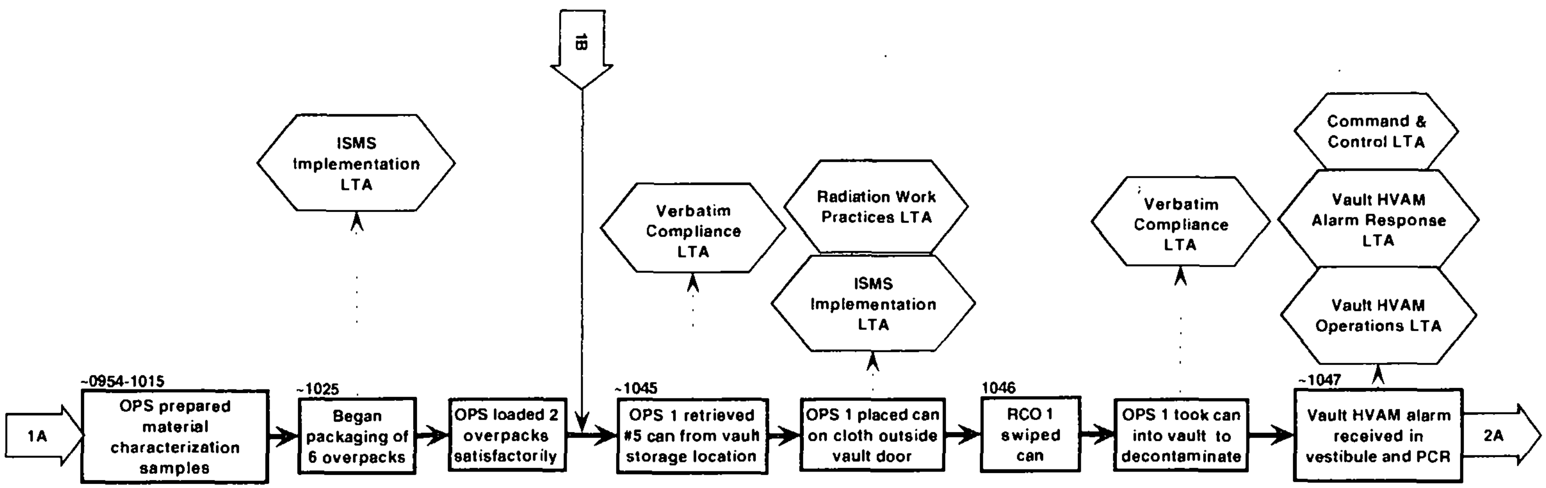

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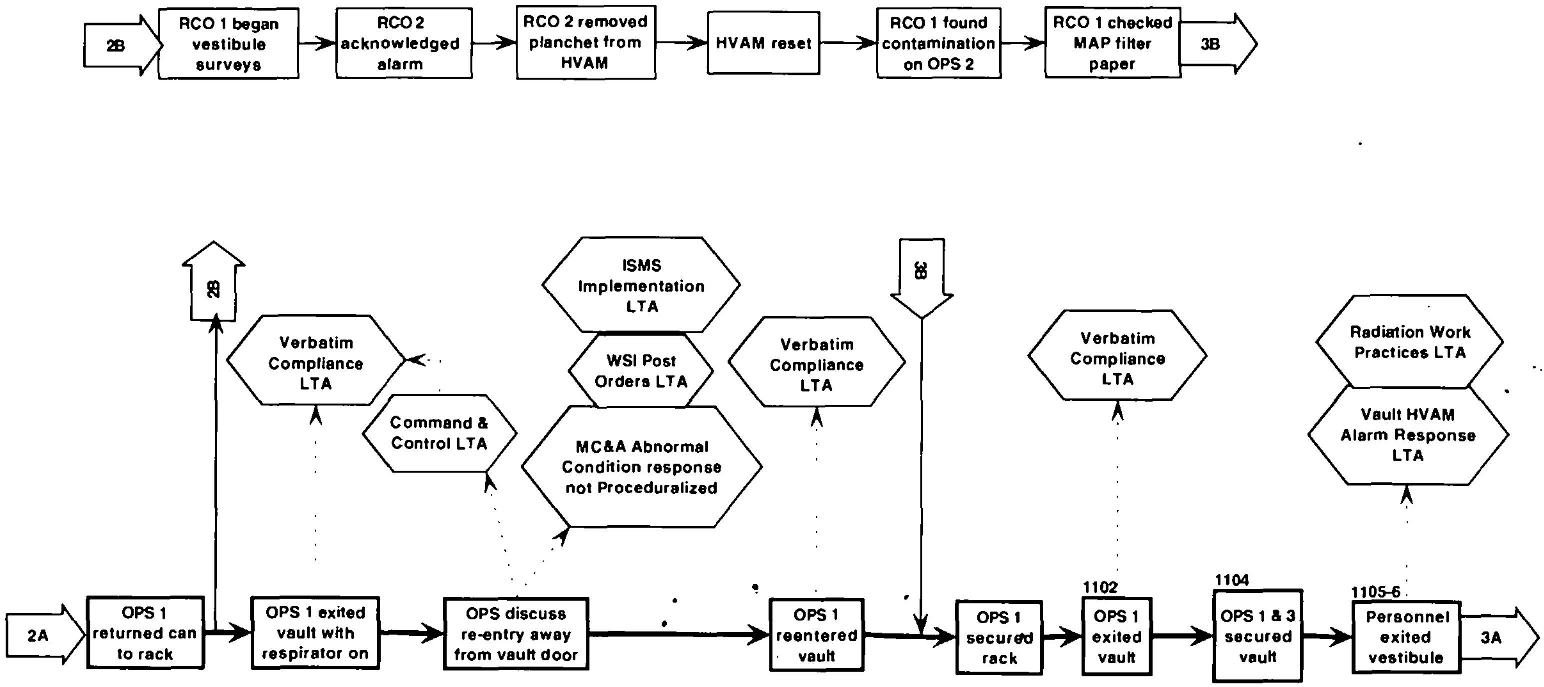

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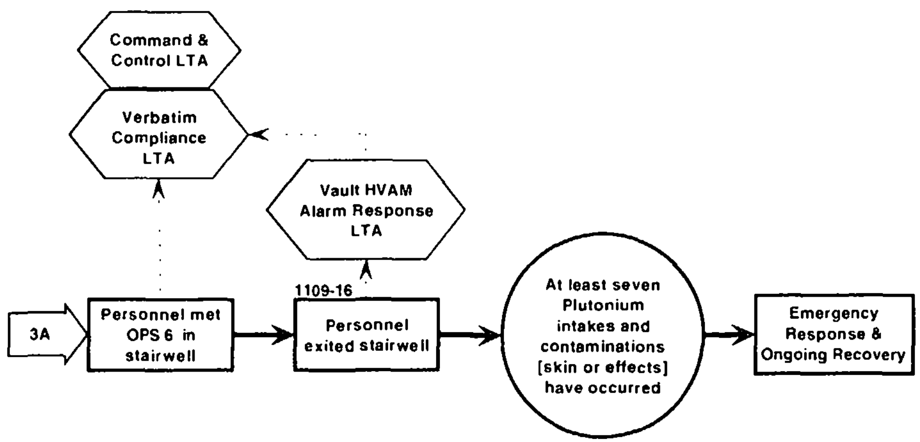

Supplemental Acronyms

BTS	Bagless Transfer System
He	Helium
LTA	Less than Adequate
PCR	Precipitator Control Room
QA	Quality Assurance