FINAL REPORT **AUGUST 1997**

TYPE B ACCIDENT INVESTIGATION BOARD REPORT OF THE JULY 2, 1997 CURIUM INTAKE BY SHREDDER OPERATOR AT BUILDING 513 LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CALIFORNIA

OAKLAND OPERATIONS OFFICE
DOE/OAK—504, Rev. 0

DOE/OAK--504, Rev. 0

This report is an independent product of the Type B Accident Investigation Board appointed by James M. Turner, Ph.D., Manager of the U.S. Department of Energy, Oakland Operations Office.

The Board was appointed to perform a Type B Investigation of this accident and to prepare an investigation report in accordance with the DOE Order 225.1, *Accident Investigations*.

The discussion of the facts, as determined by the Board, and the views expressed in the report do not assume and are not intended to establish the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party. This report neither determines nor implies liability.

On July 3, 1997, I established a Type B Accident Investigation Board to investigate the July 2, 1997, Personnel Contamination with Curium While Shredding HEPA Filters in Building 513, at Lawrence Livermore National Laboratory, Livermore, California. The Board's responsibilities have been completed with respect to this investigation. The analysis, identification of root and contributing causes, and judgment of need reached during the investigation were performed in accordance with DOE Order 225.1, *Accident Investigations.*

I accept the findings of the Board and authorize the release of this report for general distribution.

James M. Turner, Ph.D.
Manager
Oakland Operations Office

Date: ________________

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EXHIBITS

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ACRONYMS AND ABBREVIATIONS

AIB	Accident Investigation Board
Am-241	americium-241
Anti-Cs	Anti-Contamination Suits
CAM	Continuous Air Monitor
CEDE	Committed Effective Dose Equivalent
Cm-244	curium-244
cpm	counts per minute
DOE	U.S. Department of Energy
DOE/OAK	U.S. Department of Energy, Oakland Operations Office
DTPA	Diethylene Triaminine Penta Acetic Acid
EM	Environmental Management
EPD	Environmental Protection Department
ES&H	Environmental Safety and Health
FSP	Facility Safety Procedures
HAD	Hazards Assessment Document
HC	Hazards Control
HEPA	High Efficiency Particulate Air
HWM	Hazardous Waste Management
IA	Incident Analysis
ICRP	International Commission for Radiation Protection
IH	Industrial Hygienist
ISMS	Integrated Safety Management System
FSAR	Final Safety Analysis Report
FSP	Facility Safety Procedures
lfm	linear feet per minute
LL	low-level

LLNL	Lawrence Livermore National Laboratory
mCi	millicurie
µCi	microcurie
MLLW	Mixed Low-Level Waste
M&O	Management and Operating
OAK	Oakland Operations Office
OSP	Operational Safety Procedures
ORPS	Occurrence Reporting and Processing System
ORR	Operational Readiness Review
PPE	Personnel Protective Equipment
Pu-239	plutonium
RA	Readiness Assessment
REACTS	Radiation Emergency Assistance Center and Training Site
RCRA	Resource Conservation and Recovery Act
SAR	Safety Analysis Report
TSR	Technical Safety Requirement
USQ	Unreviewed Safety Question

GLOSSARY OF TERMS

Anti-Cs: Coveralls worn by workers made of a contamination-resistant material.

Barrier: Anything used to control, prevent, or impede energy flows. Common types of barriers include equipment, administrative procedures and processes, supervision/management, warning devices, knowledge and skills, and physical objects. Barriers may be control or safety barriers or act as both.

Barrier Analysis: An analytical technique used to identify energy sources and the failed or deficient barriers and controls that contributed to an accident.

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.

Blue Alpha Meter: An air proportional detector designed at LLNL for use in detecting alpha radiation. It has an active area of approximately 100 square centimeters.

Campaign 1: The shredding of HEPA filters beginning on March 7, 1997 and ending on April 1, 1997.

Campaign 2: The shredding of solidified chlorosolvents beginning on April 22, 1997 and ending on June 16, 1997.

Campaign 3: The shredding of HEPA filters beginning on June 26, 1997 and ending on July 2, 1997.

Causal Factors: All events or conditions in the accident sequence necessary and sufficient to produce or contribute to the unwanted result. Some types of causal factors are:

-*Direct cause:* The immediate events or conditions that caused the accident.

-*Contributing causes:* Events or conditions which increase the likelihood of an accident but which individually did not cause the accident.

-*Root causes:* Conditions or events which if eliminated or modified, will prevent recurrence of an accident or similar events.

Cave: A shielded glove/manipulator box used to remotely handle high levels of radioactivity or where the radiation levels are high.

Change Analysis: An analytical technique used for accident investigations, wherein accident-free references bases are established, and then changes relative to accident causes and situations are systematically identified. In change analysis, all changes are considered, including those initially considered trivial or obscure.

Committed Effective Dose Equivalent (CEDE): 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.

Continuous Air Monitor (CAM): An instrument that continuously samples and measures the levels of airborne radioactive materials on a "real-time" basis and has alarm capabilities at pre-set levels.

counts per minute (cpm): The equivalent radioactivity is derived by dividing the cpm by the instrument efficiency. The Blue Alpha Meter has an efficiency of fifty percent. As used in this report, to convert to disintegrations per minute, the cpm value should be multiplied by 2.

disintegration per minute (dpm): The rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background and efficiency associated with the instrumentation.

Diethylene Triaminine Penta Acetic Acid (DTPA): An investigational new drug used to enhance the excretion of metals, including some radioactive elements, from the body and thereby reduce their residency times.

Facility Representative: For each major or group of lesser DOE nuclear facilities, an individual or his or her designee assigned responsibility by the Head of the Field Organization for monitoring the performance of the facility and its operations. This individual will be the primary point of contact with the contractor and will be responsible to the appropriate Secretarial Officer and Head of Field Organization.

Hazards Control Team 4: One of four LLNL Environmental Safety and Health support teams organized through the Hazards Control Department. Each team, consisting of safety and environmental specialist and technicians, provide support to one or more of LLNLs eleven program areas (directorates). Team 4 provides support to the Hazardous Waste Management Division, in addition to areas within other directorates.

High Efficiency Particulate Air (HEPA) Filter: A filter used to remove 99.9% or more of particulates from an air system.

Judgments of Need: Managerial controls and safety measures necessary to prevent or minimize the probability or severity of a recurrence of an accident.

Legacy Waste: LLNLs legacy waste is the backlog of stored waste remaining from nuclear weapons research activities for which a permanent disposal determination remains to be made, or where insufficient characterization information exists to allow proper disposition.

Magnehelic Gauge: The magnehelic gauge measures the drop in air pressure across the HEPA filter (associated with the shredder's ventilation system).

micro (μ): One millionth (10^{-6}).

Mixed Low-Level Waste (MLLW): Is defined by the Federal Facility Compliance Act of 1993, as any waste containing both a hazardous waste as defined by the Resource Conservation and Recovery Act (RCRA), and source, special nuclear, or bi-product material subject to the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.).

Occurrence Reporting and Processing System (ORPS): The reporting system established and maintained for reporting occurrences related to the operation of DOE facilities.

Operational Awareness: Includes but is not limited to periodic: reviews of pertinent documents; interactions and observations; on-site visits; assessments of performance objectives; evaluating activities related to appraisals, reviews, etc.; and other activities necessary to maintain awareness for programs under their jurisdiction.

Operational Safety Procedures (OSP): Delineates controls specific to an activity, including safety responsibilities and specific operational controls necessary to ensure a low-risk work environment.

Oversight: Refers to the responsibility and authority assigned to the Assistant Secretary for Environment, Safety and Health to independently assess the adequacy of DOE and contractor performances. Oversight is separate and distinct from line management activities, including self-assessment.

Program Envelope: The range of conditions covered by the safety documentation of a process, activity or facility under which safe operation for a specific program is adequately controlled.

rem: Unit of dose equivalent.

Respirator: A mask-like device worn over the mouth and nose used to protect the wearer's respiratory system.

Root Cause: A fundamental cause that, if eliminated or modified, would prevent recurrence of the accident.

Safety Analysis Report (SAR): A report which documents the adequacy of safety analysis for a nuclear facility.

Surveillance: A form of performance-based assessments, conducted by primarily observing real-time activities and existing facility conditions, interviewing personnel, and reviewing documentation. Formal, advance notification and reporting to contractors are not required.

7A Collection Box: A metal 7 foot x 3 foot x 3 foot box used to collect, store, transport, and/or dispose of hazardous or radioactive waste.

Technical Safety Requirements: The requirements that define the conditions, safety barriers, and the management or administrative controls necessary to ensure safe operations.

Type B Accident: In this case, an accident in which the total effective dose equivalent to the worker is greater than 10 rem, but less than 25 rem CEDE.

Executive Summary

INTRODUCTION

On July 2, 1997 at approximately 6:00 am, two operators (Workers 1 and 2), wearing approved personal protective equipment (PPE), began a shredding operation of HEPA filters for volume reduction in Building 513 (B-513) at Lawrence Livermore National Laboratory (LLNL). The waste requisitions indicated they were shredding filters containing ≤1 µCi of americium-241 (Am-241). A third operator (Worker 3) provided support to the shredder operators in the shredding area (hot area) from a room that was adjacent to the shredding area (cold area). At approximately 8:00 am, a fourth operator (Worker 4) relieved Worker 2 in the shredding operation. (For this operation, shifts in the shredder area usually ranged from 45 minutes to 2 hours.) Sometime between 8:30 am and 9:00 am, Worker 3 left the cold area to make a phone call and set off a hand and foot counter in Building 514. Upon discovering the contamination, the shredding operation was stopped and surveys were conducted in the shredder area. Surveys conducted on the workers found significant levels of contamination on their PPE and the exterior of their respirator cartridges. An exit survey of Worker 1 was conducted at approximately 10:05 am, and found contamination on his PPE, as well as on the exterior and interior of his respirator. Contamination was also found on his face [which ranged from 2,000 to 200,000 counts per minute (cpm) (as used in this report, to convert to disintegrations per minute, the cpm value should be multiplied by 2)], chest, back of neck, hair, knees, and mustache. A nose blow indicated significant contamination, which was later determined to be curium-244.

ROOT AND CONTRIBUTING CAUSES

The Board determined the direct cause of the accident was the breach of respiratory protection, the exact cause of which could not be determined.

Contributing causes (causes that increased the likelihood of the intake without individually causing the intake, and that are important enough to warrant corrective action) to the intake are as follows:

- Operational Safety Procedure (OSP) was inadequate and not followed;
- Waste requisition(s) significantly mis-characterized the amount and type of radioactivity contained in the high efficiency particulate air (HEPA) filter(s);
- The Continuous Air Monitor (CAM) was not on, and
- Communications within and between Laboratory organizations failed to deliver needed information regarding wastes and the hazards of the operations.

The root cause of intake (the fundamental cause that, if eliminated or modified, would prevent recurrence of this and similar intakes) was the failure of management and supervisors to adequately analyze, control and manage the hazardous waste treatment operation.

Analysis of the root and contributing causes indicates that the origin of this intake began with the change in management and waste characterization methods which occurred in B-251, the Heavy Element Facility, before 1995, and continued through a series of missed opportunities to the date of the accident. Missed opportunities included: not fully analyzing hazards associated with shredding HEPA filters prior to embarking on a shredding program; having an inappropriately designed, not fully tested and poorly operating ventilation system; failing to recognize filter clogging as impacting ventilation, and thereby safety; not reviewing contents of the individual HEPAs prior to shredding; failing to follow the Operational Safety Procedure; and having a CAM that was not turned on.

CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of those facts and analytical results that the Board considers especially 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 directed at guiding managers in developing follow-up actions. The following table summarizes the conclusions of the Board and judgments of need regarding managerial controls and safety measures necessary to prevent or mitigate the probability of a recurrence.

CONCLUSIONS AND JUDGMENTS OF NEED	
Conclusions	**Judgments of Need**
Hazardous Waste Management failed to properly analyze hazards associated with shredding waste and failed to establish appropriate systems, procedures and controls for defense in depth. -No hazards analysis was done for glove box filters. -Ventilation system was inadequate. -Pre-start was inadequate.	**LLNL/HWM should:** 1.1 Evaluate implementation of the Integrated Safety Management System (ISMS) for Hazardous Waste Management. 1.2 Establish procedures to ensure appropriate analysis and review are performed prior to start of new operations. 1.3 Ensure operations are fully analyzed and appropriately controlled, and continuously improved.
Hazardous Waste Management failed to provide adequate supervision and management oversight to ensure operations are conducted in accord with procedures. In addition, first-line supervisors and workers were not sufficiently knowledgeable of safety procedures.	**LLNL/HWM should:** 2.1 Improve enforcement of compliance with existing operating and safety procedures. 2.2 Increase supervision and management's involvement in surveillance and performance-based assessments of operations. 2.3 Ensure personnel are appropriately trained in the use of procedures, safety equipment and alarms.
B-251 waste generator failed to accurately characterize waste.	**LLNL Management should:** 3.1 Evaluate effectiveness of current waste characterization program. 3.2 Identify other waste characterization errors and determine corrective actions where appropriate.
LLNL failed to adequately share waste characterization and hazard knowledge between organizational components.	**LLNL Management should:** 4.1 Develop and implement mechanism to share waste characterization and hazard data. 4.2 Seek input from employees with historical knowledge of operations and deficiencies in documentation.

TYPE B ACCIDENT INVESTIGATION BOARD REPORT OF THE JULY 2, 1997 CURIUM INTAKE BY SHREDDER OPERATOR AT BUILDING 513, LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CALIFORNIA

1 INTRODUCTION

1.1 Background

On July 2, 1997, a hazardous waste technician (referred to as "Worker 1") wearing approved personal protective equipment (PPE) and a full-face respirator was involved in a high efficiency particulate air (HEPA) filter shredding operation at Lawrence Livermore National Laboratory (LLNL). The worker was found to have contamination on his personal protection clothing and on the exterior and interior of his respirator. After further examination, contamination was found on his face [which ranged from approximately 2,000 to 200,000 counts per minute (cpm) (as used in this report, to convert to disintegrations per minute, the cpm value should be multiplied by 2)], chest, back of neck, hair, knees, and mustache. The contamination was later determined to be curium 244 (Cm-244).

On July 2, 1997, a worker shredding HEPA filters was found contaminated with curium-244.

On July 3, 1997, the Manager of the U.S. Department of Energy (DOE) Oakland Operations Office (OAK), James M. Turner, Ph.D., appointed a Type B Accident Investigation Board (AIB or Board) to investigate the accident in accordance with DOE Order 225.1, *Accident Investigations* (see Appendix A). The AIB commenced its investigation on July 7, 1997, with a goal of completing its investigation on August 7, 1997. However, due to delays associated with the high level of contamination found in the shredder room, and delays in analyzing Worker 1's highly contaminated respirator, an extension to the investigation was required. Dr. Turner granted an extension to the Board on August 7, 1997, and the investigation was extended to August 29, 1997 (see Appendix A).

A type B DOE Accident Investigation Board was appointed on July 3, 1997 to investigate the accident.

1.2 Facility Description

LLNL is a DOE facility under the cognizance of DOE/OAK. The Regents of the University of California (referred to as "the University") is the management and operating (M&O) contractor operating LLNL for DOE. The facility in which this accident occurred is under the programmatic direction of the DOE Office of Environmental Management (EM).

The Area 514 Facility consists of two buildings, 513 and 514 (B-513 and B-514), which is located in the southeast quadrant of LLNL. Area 514 is operated by the Environmental Protection Department's (EPD) Hazardous Waste Management (HWM) Division.

Management Facility.

B-513 houses the equipment for the shredding and solidification of hazardous, low-level (LL) and mixed low-level wastes (MLLW). The Solidification Unit includes a self-contained process optimization and treatability laboratory. The building also houses a Container Storage Unit to store liquid and/or solid hazardous, LL and MLLW.
B-513 is a pre-engineered, one-story building totaling approximately 3,500 square feet area (see Figure 1-1, Floor Plan of Building 513). Construction is of metal sheeting bolted to a steel framework on a concrete slab floor. It has five metal roll-up doors and two personnel access doors along its north side. The ventilation in the building is controlled by louvers in the east and west walls, two ceiling-mounted electric supply fans/heaters, and five passive roof vents.

B-513 houses a shredder room (Rm 1002), and an open area for a self-contained solidification unit, a chemistry room and container storage space for liquid and/or solid hazardous, radioactive, and mixed wastes (Rm 1000). Room 1002 has 692 square feet of space and houses the Shredder Unit and its auxiliary equipment. A louvered ventilation opening is present on the east wall of the room while a passive roof vent is mounted in the ceiling. The shredder room has a roll-up door that is located on the north wall and a personnel entrance/exit door located on the inside (west) wall. This wall extends to within approximately one foot of the ceiling and delineates the "hot" area (the shredder room) from the "cold" area (the rest of the building).

1.3 Scope, Conduct, and Methodology

The purpose of the investigation was to investigate the cause of the accident and develop judgments of need to prevent recurrence.

The scope of the Board's investigation was to investigate the causes of the accident in accordance with DOE O 225.1, *Accident Investigations.* The Board also evaluated the adequacy of the DOE and contractor's safety management system and work control practices. Based on the ensuing investigation, the Board identified judgments of need for corrective actions to prevent the recurrence of similar events.

The objectives of the investigation were to: 1) determine the cause of the accident, including deficiencies, if any, in safety management systems; 2) to assist DOE in identifying and understanding lessons

Shredding Operations were conducted in a LLNL Hazardous Waste

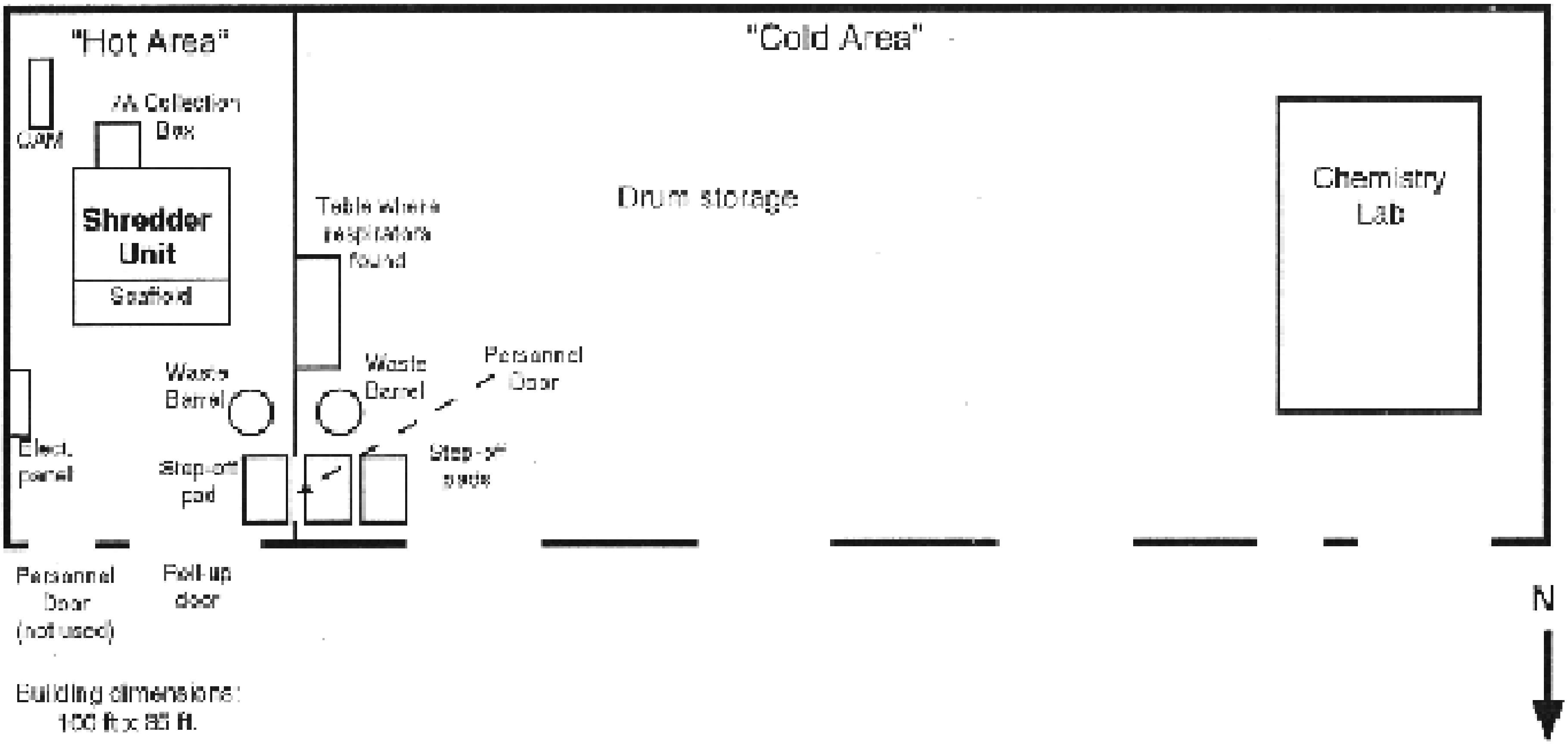

Figure 1-1: Floor Plan of Building 513

learned to promote safety improvement; and 3) to reduce the potential for similar accidents. The Board conducted its investigation, focusing on management systems, using the following methodology:

- The Board conducted extensive interviews with key personnel, viewed videotapes of the accident scene, and reviewed pertinent documentation and policies.
- Event and causal factors charting[1], along with a respirator analysis, a barrier analysis[2], and change analysis[3], were used to provide supportive correlation and identification of the accident's causes.

2 FACTS AND ANALYSES

2.1 Chronology and Accident Description

A chronology of key events that lead to the accident, as well as a description of the accident, are provided in Sections 2.1.1 and 2.1.2.

2.1.1 Chronology

A time-line documenting key events that lead up to the July 2, 1997 accident is illustrated in Figure 2-1, Summary Events Chart and Accident Chronology.

2.1.1.1 Waste Generator

The HEPA filter believed to be the source of the contamination, originated in B-251 where nuclear research activities had been conducted for many years. Records indicate that the suspect HEPA filter came from one of two sources in B-251. The filters were removed from service, wrapped in plastic and placed in two 7A boxes outside the facility to await transport. Waste requisitions were completed and one box was picked up and transported to the Hazardous Waste Management (HWM) yard in October of 1994, while the second box was transferred in June of 1995.

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[1] Charting depicts the logical sequence of events and conditions (causal factors) that allowed the events to occur.

[2] Barrier analysis reviews hazards, the targets (people or objects) of the hazards, and the controls or barriers that management control systems put in place to separate the hazards from targets. Barriers may be administrative, physical, or supervisory/managerial.

[3] Change analysis is a systematic approach that examines barrier/control failures resulting from planned or unplanned changes in a system.

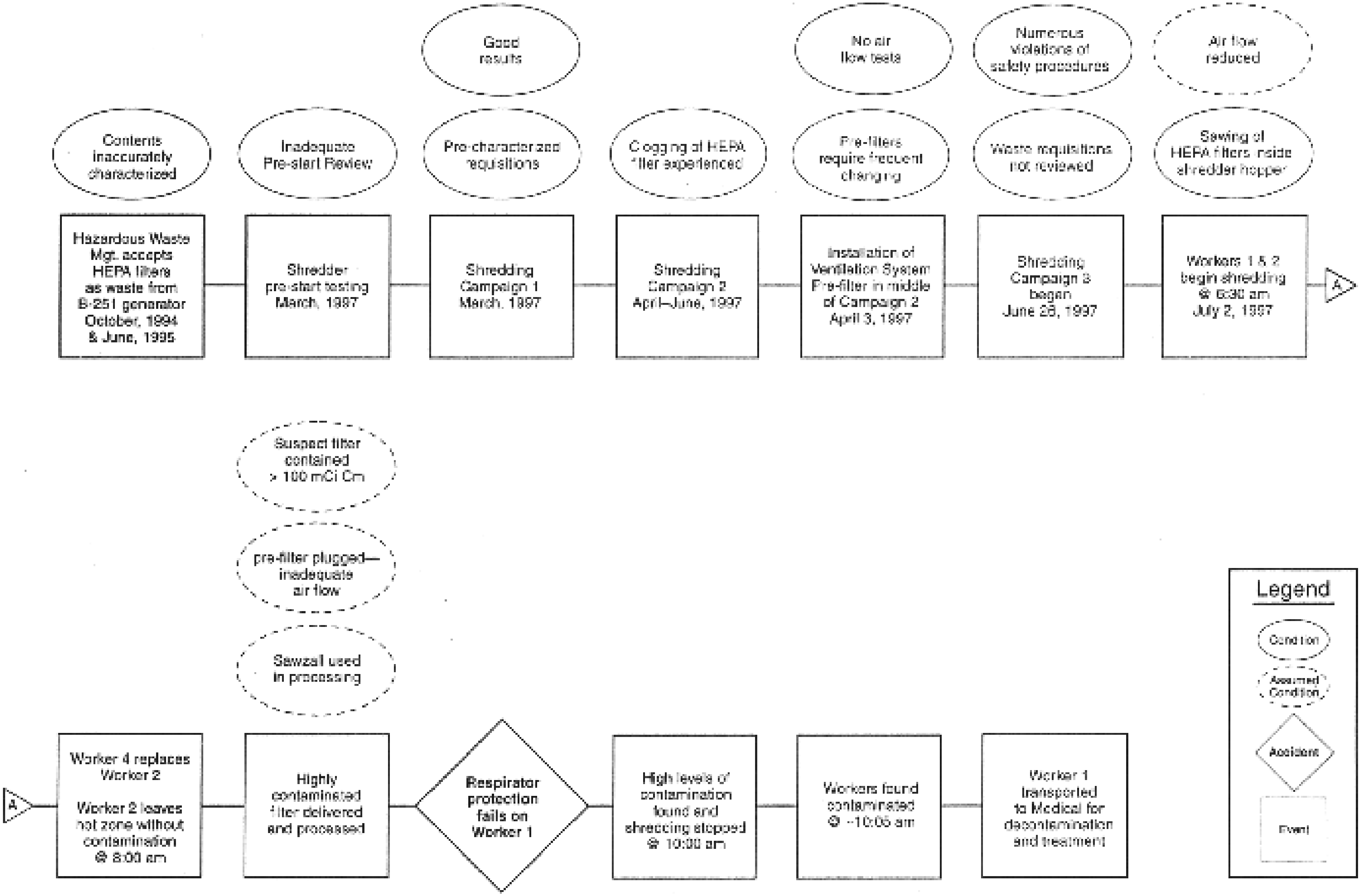

Figure 2-1: Summary Events Chart and Accident Chronology

Just prior to the change-out of the suspect filter, characterization practices for waste HEPA filters had been changed at this building. Gamma spectroscopy had previously been used to identify and quantify the radioactive constituents in waste HEPA filters. This practice was abandoned because it was not believed to be accurate. However, no alternative characterization method was substituted. Instead, it appears that a value of <1 µCi of Am was used for all requisitions processed after this time. Generator management appears to have completely underestimated the importance of waste characterization to safety. No effort was made to use the process knowledge of the experimenters to aid the characterization process.

HEPA filters were not characterized by the generator when they were removed from B-251.

2.1.1.2 Shredding Operations

For several years, LLNL has undertaken a major effort to characterize, treat, and dispose of radioactive legacy waste. LLNLs legacy waste is the backlog of stored waste for which a permanent disposal determination remains to be made, or where insufficient characterization information exists to allow proper disposition. The HEPA filters from B-251 were considered to be legacy waste.

Based on waste minimization goals and cost saving initiatives, LLNL made a decision to shred mixed low-level waste (MLLW). In the case of HEPA filters, managers stated that shredding was undertaken to facilitate characterization, as core-drilling each filter was seen as time consuming and inherently dangerous.

The Shredding Unit was originally designed to shred metals (see Exhibit 2-1). Following modifications, the Shredding Unit was used to shred MLLW solids such as HEPA filters, debris, and empty containers, reducing them to smaller pieces to facilitate packaging and consolidation. The modification allowed the shredded waste to drop into a 7A waste collection box. A ventilation system was added by LLNL when the shredder was originally installed to keep airborne particulate matter generated during the shredding process within the system. During operation, a blower pulls air through the hopper at the in-feed chute and out through a HEPA filter to the outside of the building. The shredder operation is permitted by the State of California as a RCRA physical treatment unit.

The Shredding Unit, originally designed to shred metals, was modified by LLNL prior to shredding HEPA filters.

The shredder ventilation system was tested by using visible smoke tests and by measuring air flow. A LLNL Industrial Hygienist advised that the air flow through the HEPA system was too low and that a bigger blower and larger duct work should be installed. While this recommendation was not implemented, a decision was made to

The shredder's ventilation system was tested and altered.

change the gearing on the ventilation system motor to increase fan speed and air flow. The need for an alarm on the magnahelic gauge (monitoring the ventilation system's HEPA filter) was also noted at this time. These changes were completed by March 13, 1997.

As required per the OSP, LLNL Hazards Control (Team 4) conducted reviews of the waste requisitions before operations and a Team 4 technician verified the operational viability of the Continuous Air Monitor (CAM) inside the shredder room. The approved filters were then shredded from the least to the most contaminated to test the effectiveness and safety of the process. No filters from glove boxes were shredded in Campaign 1. For this campaign (and all subsequent campaigns), the CAM detection window was set in anticipation of americium-241 (Am-241) and plutonium-239 (Pu-239).

Exhibit 2-1: Shredding Unit in B-513 (prior to dry run).

To reduce the spread of contamination for all three campaigns, a curtain of plastic sheeting was hung just beyond the main entry door in the shredder room and several layers of plastic sheeting were placed on the floor and approximately 8 to 12 feet up the walls. An area of about 10 ft. by 15 ft. immediately outside the shredder room

To reduce the spread of contamination, plastic was placed on the walls and the floor of the Shredder Room.

personnel door (in the cold area) was also covered in plastic. To prevent contamination from leaving the shredder room, a “sticky” or “step-off” pad was placed on the floor of the shredder room just in front of the personnel door. Likewise, two step-off pads were placed on the opposite side of the door in the cold area. At the end of the campaigns, the plastic was removed and replaced and the shredder room was decontaminated.

Filters to be shredded were delivered to B-513 by a fork lift using the roll-up door. The filters were stacked just inside the roll-up door on pallets until they were processed. Some filters were wrapped in clear plastic bags, and the wrapping was removed one bag at a time as the filters were carried to the shredder for processing. Other filters had their duct ports taped, but had no plastic bags or other containment. This wrapping was bagged-up immediately after being removed and was segregated as a low-level only waste stream (see Exhibit 2-2).

Exhibit 2-2: HEPA filter discovered on the scaffolding platform

(adjacent to shredder) after the accident. Masslin cloth was placed on the scaffolding during post-accident re-entry procedures to prevent spread of contamination.

Campaign 1

Characterized HEPA filters were successfully shredded during Campaign 1.

The first shredding campaign began on March 7, 1997. Authorized tools that were utilized in Campaign 1 included a large, metal pry bar to manipulate the filters in the hopper and a rake to distribute the shredded material in the receiving box. All of the HEPA filters that were shredded in Campaign 1 were cored, sampled, and characterized for hazardous and radioactive constituents. Workers checked themselves for contamination using a radiation monitor which was kept in the cold area. A meeting was held to review safety procedures prior to the start of Campaign 1. No significantly elevated levels of contamination were found in the shredder room. Campaign 1 ended on April 1, 1997. The process was considered to have been a success.

Campaign 2

The second campaign started April 22, 1997 and focused on processing solidified chlorosolvent MLLW stored in 55-gallon drums. Team 4 was notified of the start of Campaign 2, and a Hazards Control technician indicated the CAM was on during the campaign. The workers used a "Sawzall" (a hand-held electric reciprocating saw) and a pneumatic chisel to open the drums.

Greater levels of dust were observed during Campaign 2 than in Campaign 1. The HEPA filter on the shredder's ventilation system had to be changed at least once. The dust generated by the shredding of the solidified chlorosolvent was finer than that from the HEPA filters of Campaign 1. The lighter particles were more easily carried through the ventilation system into the HEPA filter. Options were considered to protect the HEPA filter and prevent clogging from becoming a maintenance concern.

To protect the HEPA filter within the shredder's ventilation system, a pre-filter was added.

To protect the HEPA from the excessive dust, the ventilation system was modified sometime in May 1997 by adding a pre-filter between the shredder and the HEPA. The pre-filter, similar to a furnace-type filter, was designed to prevent large airborne particles from plugging the HEPA. The pre-filter succeeded in protecting the HEPA, but frequently became plugged, requiring several changes during the day. The workers relied on visual observations (such as excessive dust in the hopper, or around the waste collection box) to indicate when the pre-filter needed changing. This change to the ventilation system was also not inspected by an Industrial Hygienist to evaluate air flow effects (see Exhibit 2-3).

Campaign 2 ended on June 16, 1997. Although contamination levels were higher at the end of this campaign than in the previous campaign, the levels were considered to be low and manageable.

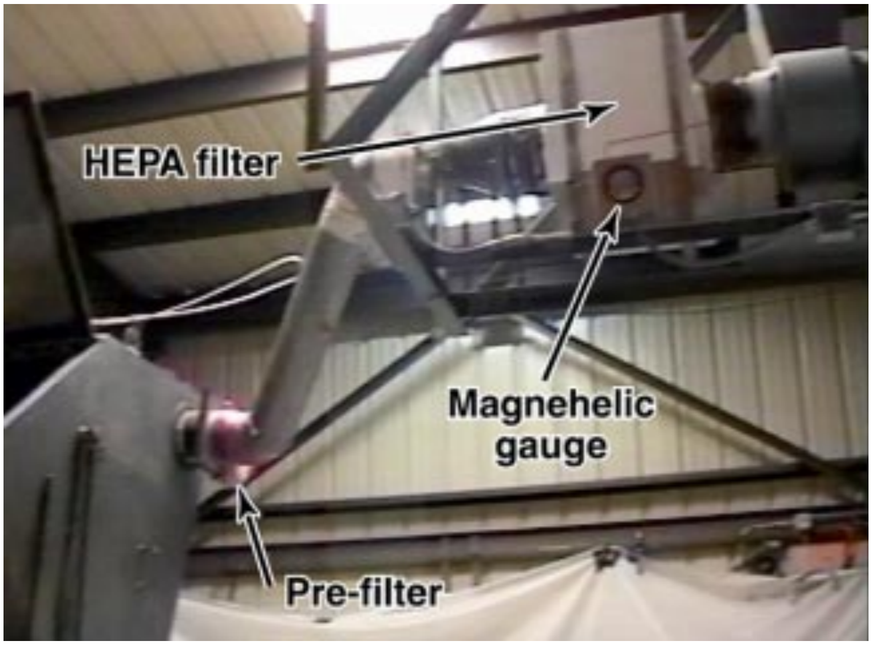

Exhibit 2-3: View of the Shredder's Ventilation System (following modifications and after the accident).

Campaign 3

The focus of Campaign 3, which began on June 26, 1997, was to process MLLW HEPA filters. The HEPA filters for this run were not characterized by HWM. No data on the filters (relating to characterization or physical description) was sent to the Team 4, nor were they informed of the start of the third campaign. Based on the information in the waste requisitions, the workers were expecting minor levels of Am and Pu contamination. No meeting was held to review safety procedures prior to the start of Campaign 3.

HEPA filters shredded during Campaign 3 were not characterized by Hazard Waste Management.

During or just before this campaign, the CAM was moved to a new location in the shredder room because it was in the way of the workers. Although the Team 4 Hazards Control technician approved of the move, he did not participate in the move, nor did he ensure that the CAM was operational. During Campaign 3, the workers utilized the Sawzall to facilitate the shredding of the HEPA filters. By cutting into or roughing up the edges of the filters, the teeth on the shredder cutting blades were able to get a better "bite", greatly reducing the time it took to process them. Some filters were cut through their entire length. Cutting was done with the shredder stopped, while the filters were in the hopper. The OSP authorized the use of the Sawzall for opening drums containing stabilized waste, it did not authorize the use of the Sawzall on HEPA filters. Surveys for personal contamina-

A Sawzall was used to facilitate the shredding process.

tion were performed infrequently, if at all, while in the shredder room, but were done upon exiting the room.

On July 1, 1997, the 7A collection box under the shredder was changed out and replaced with an empty one. Broad area swipes were taken in the shredder room at the end of the work day. The samples confirmed that there was no contamination at that time.

For this campaign, no samples of the filters to be shredded were taken. Instead, a characterization profile was used. This profile, and its intended use, were not discussed with Team 4. To create the profile, characterization data was taken from about 150 HEPA filters and sorted by building of origin. This database indicated that only very low levels of contamination could be expected from all buildings. Good agreement was noted between the information on the requisitions and the actual data. Each filter to be shredded in Campaign 3 was assumed to have similar types and levels of contamination as the filters in the data base from the same building. However, the profiles were based only on data from room and building filters. No data from glove box HEPA filters was available, and these filters are much more likely to be highly contaminated.

The characterization profile used was based on building filters and did not include glove box filters.

2.1.2 Accident Description

On July 2, 1997, work began at 6:00 am with Worker 1 and Worker 2 dressing in anti-contamination suits (anti-Cs) to enter the shredder room. The daily pre-operational review was conducted and logged. The workers assumed the CAM was operational because they heard the sound of the air flow pump. The ventilation system pre-filter was changed out before beginning operations. Shredding started at approximately 6:30 am. No portable radiation meter was present for use in the shredder room, however an alpha meter was available in the adjacent cold area. Worker 3 was working immediately outside the shredder room roll-up door, wiping down the 7A collection box that had been removed from the shredder room the previous day.

The shredding operation began at about 6:30 am on July 2, 1997.

The shredder's pre-filter was changed a second time by Worker 2 after processing about eight filters (after less than 1.5 hours of use).

At about 8:00 am, Worker 4 replaced Worker 2 in the shredder room. Upon exiting the room, no contamination was found on Worker 2 or his clothing.

Work continued in the shredder room. Throughout the morning, Worker 1 was doing most of the processing work on the elevated scaffold near the hopper, including use of the Sawzall (see Exhibits 2-4 and 2-5). When necessary, a hand-held garden-type pump sprayer filled with a soap and water mixture was sprayed into the hopper and waste collection box to control dust. From testing conducted after the accident, it was determined that the pump sprayer was not working, probably because it was out of liquid. Using a fork lift, Worker 3 delivered a 7A box of HEPA filters to the roll-up door at about 8:30 am. The door was opened from the inside by Workers 1 and 4, and Worker 3 transferred the HEPAs in the box to the workers without entering the shredder room. It is unclear whether any swipes were taken prior to the roll-up door being opened.

Exhibit 2-4: Shredder workers lifting HEPA filter into shredder hopper (during dry run).

The suspect HEPA filter was shredded between 8:30 and 9:30 am.

It appears that some time between 8:30 am and 9:30 am, the suspect HEPA filter was processed. The most likely source of the contamination was a glove box filter listed on requisition No. R-022841 (signed off on June 15, 1995) or a cave filter from requisition No. R-022605 (signed of on October 27, 1994) from B-251. It was known by past workers in B-251 that both the glove box and cave had been used to process very high levels of Cm, and the suspect HEPA filter may have contained in excess of 100 mCi. Cm has a high specific activity and is not commonly used in the DOE Complex. At about 9:30 am, Worker 3 left the cold area to make a phone call. The hand and foot counter at the exit of the Area 514 yard indicated contamination on both of his feet and his right hand**.** Upon rechecking, only his left shoe was contaminated, and it could not be decontaminated. Worker 3's contamination was verified by a HWM supervisor (Responder 1) and a HWM technician (Responder 2) at about 200 cpm using a portable alpha meter. Worker 3 thought the alarm was likely due to radon daughters, which will occasionally give readings which are unrelated to the work being performed. Worker 3 changed his shoes, made his phone call, and prepared to return to work.

Worker 3 set off a hand and foot counter in Area 514.

Exhibit 2-5: Shredder worker with shredder hopper door open (during dry run).

In the meantime, Responders 1 and 2 began surveying the area

outside of B-513 to determine if any contamination had occurred. The forklift and Worker 3's pathway through the yard of Area 514 were checked and no contamination was found. Worker 3 donned his PPE and entered the shredder room to begin his shift. Upon learning of potential contamination, Worker 1 asked Worker 4 and Worker 3 to take swipes of the area in front of the shredder to check for contamination, handing the samples out the main entry door to be read by Worker 2 in the cold area. Swipes were taken using

Kimwipes and read with an alpha meter which indicated contamination levels as high as 4,000 cpm alpha on the doorway inside the shredder room and 40,000 cpm on portions of the shredder room floor. Preliminary attempts were made to decontaminate the door area and the floor with little success.

Contamination was confirmed in the Shredder Room.

Because of widespread contamination, the workers decided to leave the area. Shredding operations were suspended at about 10:00 am. Worker 1 was first to remove his anti-Cs inside the shredder room. Worker 4 and Worker 3 assisted Worker 1 in rolling off his anti-Cs and placed them in the waste barrel inside the shredder room. Worker 1 then exited through the personnel door into the cold area. Worker 4 was next, with Worker 3 being the last to leave the shredder room. Worker 2 and Responders 1 and 2 were present in the cold area to assist in surveying the workers as they exited the shredder room.

Shredding operations were suspended at about 10:00 am.

After exiting the shredder room, Worker 1 removed his respirator and significant contamination was found on it. Worker 1 removed the respirator cartridges, surveyed them, and again found elevated readings. Additional contamination was found inside his respirator. The contamination level on his face ranged from 2,000 to 200,000 cpm. Even after disrobing to his undergarments, contamination was still found on his chest, hair, face, moustache, back of his neck, and knees. A nose blow was obtained and a check with an alpha probe gave a reading of 11,000 cpm. Subsequently, alpha spectroscopy of the sample identified the nuclide to be Cm-244, believed to be in the form of curium oxide.

Upon exiting the Shredder Room, Worker 1 was found to be contaminated.

Worker 4 was found to have small amounts of contamination on his inner work clothes, but none on his skin or face. Worker 3 was found to have contamination on his overalls, but none on his inner clothing, skin, or face.

Worker 1’s respirator and two cartridges were placed in the contaminated trash barrel in the cold area. The respirators from the three other workers were placed on the table in the cold area, while their six filter cartridges were also placed in the waste barrel.

The assigned Hazards Control technician (Responder 3), who happened to be in Area 514 at the time of the accident, was notified about the contamination incident. The technician arrived before the initial frisking of the four workers had been completed. Other technicians arrived soon after. While some of the Hazards Control personnel attended to the contaminated workers, others began to assess the extent of contamination in B-513. Gross swipes were taken at various locations around the western portion of the building with only background readings found. The yard in Area 514 was again checked for contamination.

When all personnel had left B-513, the circuit breaker controlling the shredder and its ventilation system was turned off, and the building was marked “off-limits” and locked. Later in the day, the shredder’s ventilation system was turned on again to provide air flow to the shredder room, and thereby reduce the risk of contamination spreading.

2.1.3 Post Accident Information

Through five separate re-entries, significant information was obtained about conditions in the shredder room at the time of the accident. A high-volume air sampler was brought into the building to monitor the potential spread of airborne contamination to the cold area.

With the exception of the step-off pad area immediately near the personnel door to the shredder room, the cold area of B-513 was found to be only slightly contaminated above the background levels. The area immediately outside the main door was found to have slightly elevated levels, with gross swipes reading from 900 to 1,800 cpm alpha. Five respirators (without filter cartridges) were found on the table in this area. Two of these respirators were determined not to have been worn by the shredder workers. Four of the respirators had low-levels of contamination on the exterior, ranging up to 400 cpm, with no interior contamination. The fifth respirator, labeled with the name of Worker 4, had readings of up to 5,000 cpm on the faceplate, but again, no interior contamination was found. The respirator used by Worker 1 was found in the waste barrel in this area.

Widely spread contamination was found in the shredder room.

The interior of the personnel door into the shredder room was found to have contamination as high as 10,000 cpm. The plastic curtain draped just beyond the door opening had contamination of up to 12,000 cpm. A survey of the shredder room found widespread, high levels of contamination (see Figure 2-2, Direct alpha meter readings taken in the Shredder Room). The majority of readings on the floor and other flat surfaces read from 10,000 to 80,000 cpm.

The area in front of the roll-up door where the HEPA filters had been unwrapped had direct readings of 200,000 to 300,000 cpm. The scaffolding platform directly in front of the shredder hopper had areas

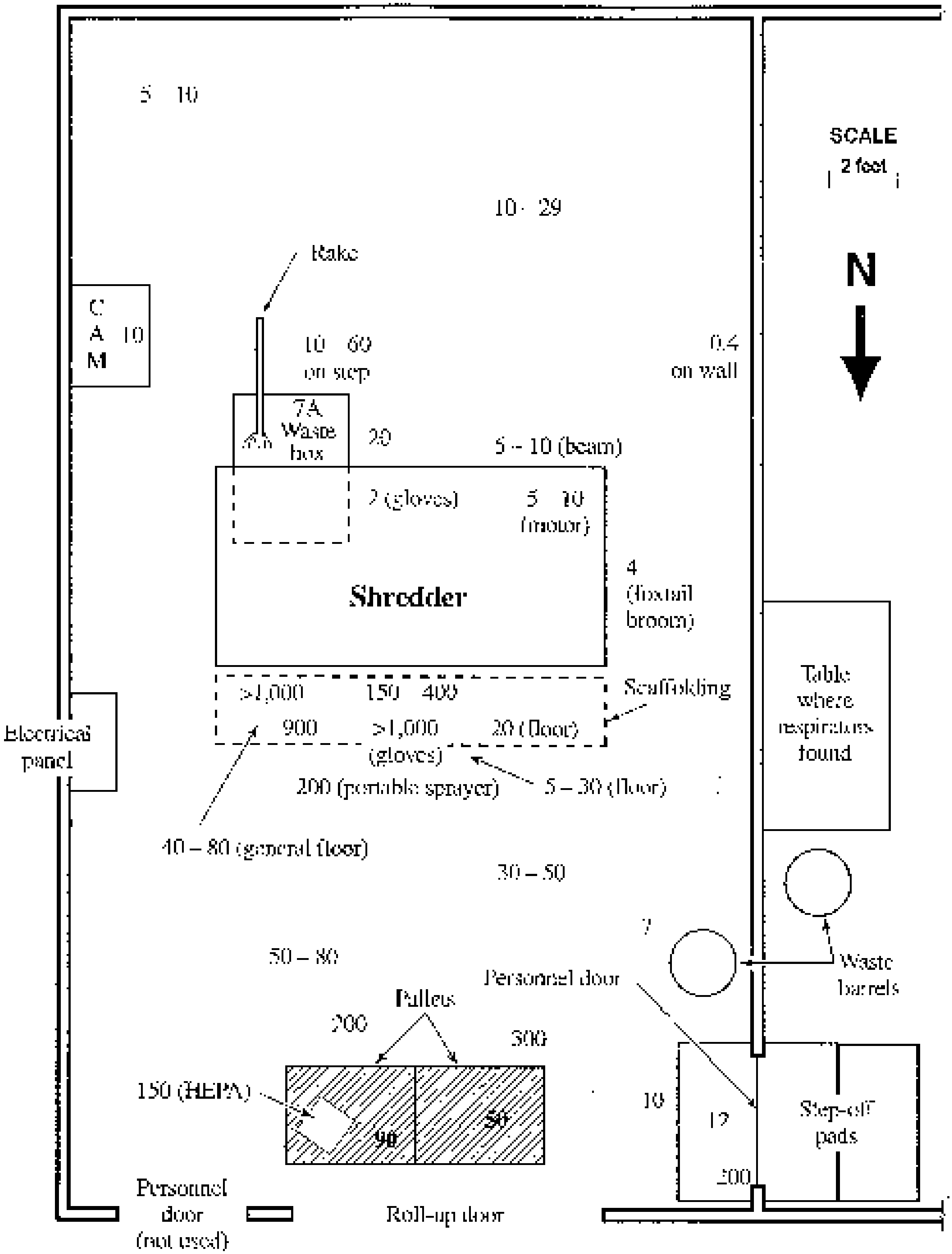

Figure 2-2: Direct alpha meter readings taken in the Shredder Room following the accident. Direct readings are × 1k cpm.

that were off-scale for the portable alpha meter being used, indicating readings over 1,000,000 cpm. A pair of outer leather work gloves found on the scaffolding platform also read off-scale. The Sawzall was found on the platform in front of the shredder hopper. The saw had readings on its motor housing that were off-scale, as did a used blade that was found. Based upon the contamination level found on the Sawzall, it seems probable that the Sawzall was used to cut into the suspect filter (see Exhibit 2-6).

Exhibit 2-6: Re-entry technician holding the Sawzall (following

the accident).

Smoke tests indicated that little or no air was flowing through the shredder's ventilation system do to a clogged pre-filter.

Smoke tests conducted by the re-entry team indicated that little air was flowing through the shredder's ventilation system due to a clogged pre-filter. The pre-filter was changed and found to be very dirty and extremely contaminated. Within minutes of being changed, the new pre-filter clogged up and the air-flow again returned to near zero. A second pre-filter change was made to restore adequate ventilation to the room.

The CAM was found to be turned off.

During the first re-entry, although the pump on the air intake for the CAM was operating, the CAM itself was found to be turned off. When the CAM was turned on by a Hazards Control technician, the audible alarm sounded. The alarm was turned off and the filter paper was changed. After being removed, the filter paper collected from the CAM read approximately 20,000 cpm on a portable alpha meter.

The 7A transport box that originally contained the suspect contaminated material was surveyed with an alpha meter. Only a single “hot spot” was found inside the box and a level of 50,000 cpm was indicated.

Direct readings ranging up to 30,000 cpm were found on the top of the wall separating the shredder room from the rest of B-513. Air sampling in the yard of Area 514 indicated airborne contamination levels slightly above minimum detectable levels. A large area swipe of the interior of the roof vent gave a reading of 1,000 cpm alpha.

The facility was released back to the LLNL HWM program for decontamination on July 22, 1997.

2.1.4 Emergency Response

To prevent further contamination, Worker 1 was dressed in anti-C’s and placed in a truck for transport to LLNLs Health Services Center at about 10:45 am. The other three workers and two responders were released from the scene, allowed to shower and change, and return to work.

Upon arriving at the Health Services Center, Worker 1 was taken to the Decontamination Room for further contamination surveys and decontamination. Contamination was found on Worker 1's head, chest, neck, mustache, nostrils, chin, and back of the head. The contamination levels ranged from 120 cpm at the back of the head to 190,000 cpm on the bottom of the chin.

Worker 1 was transported to LLNLs Health Services Center where his condition was assessed and treatment given.

Preliminary gross alpha counts on two nasal swabs collected from Worker 1 were found to be 9,500 and 3,700 cpm respectively. Subsequent alpha spectroscopy of these samples identified the radionuclide as Cm-244. Later that afternoon at about 1:00 pm, nasal swipes were taken from the other workers and responders to check for contamination. Readings were at or below detection limits. Subsequent but preliminary bioassay results indicate minimal to moderate intakes for these workers.

A LLNL Hazards Control internal dosimetrist reviewed the available information concerning both the level and type of contamination for Worker 1. On this basis and specified LLNL criteria, the dosimetrist recommended that the chelating agent Diethylene Triaminine Penta Acetic Acid (DTPA) be administered. The attending Health Services physician concurred and began treatment after consulting the Radiation Emergency Assistance Center and Training Site (REACTS) in Oak Ridge, Tennessee. Additional skin decontamination of Worker 1 was also undertaken at this time.

Lung counts performed on Worker 1 on the afternoon of July 2, and again on July 3 were inconclusive due to the presence of low-levels of residual external skin contamination and the low energy of the x-rays emitted by Cm-244. At approximately 5:00 pm on July 2, Worker 1 was released to return home after all surface skin contamination had been removed.

Worker 1, and the other three workers, were placed on a comprehensive follow-up bioassay program. Initial estimates of the internal dose Worker 1 received are in the range of 15 to 30 rem committed effective dose equivalent (CEDE). The corresponding range of committed dose equivalent to the bone surface is 250 to 500 rem. As is typical in cases of intakes of transuranic materials, the assessment of the intake and dose (which will be based upon follow-up bioassay samples) is expected to take six to twelve months. Worker 1 has been restricted from further work involving radioactive materials until his status with respect to dose limits can be more accurately measured.

Workers were placed on a bioassay program.

Bioassay samples were also collected from Workers 2, 3 and 4 and Responders 1 and 2. These samples have confirmed small, but significant levels of intake [from 0.01 to 1.5 rem (CEDE)] for the other three workers, as well as for one of the first responders. Additional follow-up bioassay samples will be collected in order to assess the intakes and doses.

It should be noted that the intake estimates are preliminary and are based on results from only the first 15 days of sampling. The route of intake for each worker appears to be largely inhalation. Both International Commission on Radiation Protection (ICRP-26/30) respiratory tract and systemic models (current) and new (ICRP-66/71/67) are being used to assess the intakes and doses. For regulatory purposes, the weighting factors provided in ICRP-26 will be used to calculate the CEDE.

The overall quality of the emergency response effort was satisfactory.

2.1.5 Investigative Readiness

On the afternoon of July 2, 1997, LLNL formed a Type C Incident Analysis (IA) team composed of LLNL and DOE/OAK employees. The IA took control of the accident scene (B-513), secured evidence, and began interviews with workers and responders. Interviews continued on July 3 in order to obtain information close to the time of the accident. LLNLs initial response to the accident was satisfactory.

During an IA interview immediately following the accident, Worker 1 described feeling a breath of fresh air sometime that morning while leaning over the shredder hopper. He checked the fit of his respirator by doing a negative pressure fit test (placing his hands over the outer surface of the respirator cartridges and breathing in). The fit test worked and Worker 1 returned to work. In later AIB interviews, Worker 1 could not remember the incident and was unsure it had happened.

An Unusual Occurrence Report was filed by LLNL on July 3. Based on this initial report, the Level B AIB was assembled by DOE/OAK to investigate the accident. The Board arrived on site on July 7 and began the accident investigation. The transition between the IA and the AIB was facilitated by LLNL and DOE/OAK employees who served as Advisors to both groups. The LLNL IA team was disbanded.

2.2 Analysis of Integrated Safety Management, Personnel Performance, and Management Systems

In reviewing this accident, the Board analyzed the implementation of the Integrated Safety Management System (ISMS), examined the suitability of personnel to perform their functions, and evaluated the management systems used by LLNL.

As part of the Board's analysis, Occurrence Reporting and Processing System was reviewed. The search did not identify any other similar occurrence reports.

2.2.1 Integrated Safety Management

The objective of integrated safety management is to assure that the DOE and its contractors systematically integrate safety into management and work practices at all levels. The core functions of integrated safety management provides a structure for any work activity that could potentially affect the public, the workers, and the environment. The functions are applied continuously to the degree deemed appropriate based on the type of work activity and associated hazards. Safety management activities can be grouped into five core safety management functions. They are:

The DOE Implementation Plan for Integrated Safety Management was used to guide the investigation.

- *Define the Scope of Work*: missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.
- *Analyze the Hazards*: hazards associated with the work are identified, analyzed, and categorized.
- *Develop and Implement Hazard Controls:* applicable standards and requirements are identified and agreed upon, controls to prevent/mitigate hazards are identified, the safety envelope is established, and controls are implemented.
- *Perform Work within Controls:* readiness is confirmed and work is performed safely.
- *Provide Feedback and Continuous Improvement:* feedback information on the adequacy of controls is gathered, opportunities for improving the definition and planning of work are identified and implemented, line and independent oversight is conducted, and if necessary, regulatory enforcement actions occur.

The analysis of this accident was guided by the DOE Implementation Plan for Integrated Safety Management, dated April 18, 1996. The following sections reflect the analysis of the relationship of the Board's causal factors and findings during this investigation to each of the five core functions of integrated safety management.

Additionally, the seven Guiding Principles[4] for DOE Safety Management were utilized for evaluating line management's performance in ensuring effective safety management.

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[4]DOE Guiding Principles for Safety Management include:

1. Line Management responsible for safety.
2. Clear roles and responsibilities.
3. Competence commensurate with responsibilities.
4. Balanced priorities.
5. Identification of safety standards and requirements.
6. Hazard controls tailored to work being performed.
7. Operations authorization.

2.2.1.1 Define the Scope of Work

The scope of work for the shredder operation was initially described in the LLNL Safety Analysis Review for Hazardous Waste Management Operations. This document describes shredding operations in general terms. For example, materials to be shredded were described only as "solid mixed wastes, such as debris and empty containers."

The idea to shred HEPA filters appears to have developed from discussions between the Legacy Waste Program Manager and Hazardous Waste Management Facility Operations personnel. These operational discussions needed to be balanced with safety considerations, as discussed in Guiding Principle number 4, which emphasizes the importance of "Balanced Priorities" in planning work. The safety consideration lead to the development of the OSP, in which the work scope is more specifically defined as including "HEPA filters, gypsum cement stabilized chlorosolvents, and classified debris." Discussions with managers indicated that they believed only building and room HEPA filters were to be shredded. Managers interviewed indicated that other types of HEPA filters would not have been approved due to the high probability of encountering significant contamination.

The scope of work could have been better defined.

The Board has concluded that the scope of work for the operation should have been better defined to explicitly state what types of HEPA filters would be acceptable.

2.2.1.2 Identify and Analyze the Hazards

DOE Order 440.1 requires an assessment of the workplace to determine whether hazards are present, or are likely to be present.

The hazards of this operation were outlined in the OSP. The hazards identified included radiation and hazardous materials. The OSP states, in part, "There is a potential for employees to be exposed to radioactive and/or hazardous materials via inhalation or ingestion when handling wastes being shredded." Other hazards identified include mechanical injury from power tools, the shredder itself, and excessive noise. Records indicate that all workers were aware of the hazards likely to be present during shredder operations.

Although the types of hazards were identified, there is much about the operation that indicates the level of hazard or risk was underestimated by LLNL management and the workers. For example, the shredder room itself appears to be inappropriate for the risk-level of the operation. There is a passive exhaust vent in the roof, open louvers on the east wall, and a 1-foot gap between the inner (west) wall and the ceiling.

The multiple violations of the OSP by both Line Management and the workers is also indicative of a perceived low-risk level of operation. The OSP reflects this as well when it specifies a relatively low-level of PPE, such as single layer anti-Cs and half-face respirators (workers chose to wear full-face respirators).

The perceived low-level of risk seems to have been based on the assumption that only wastes with < 1 mCi per 7.5 cubic feet would be processed. This would have been a valid assumption had robust controls been in effect to make it highly unlikely this limit would be exceeded. In this case, controls on this limit were very weak, and the assumption of a low-risk was not appropriate.

The Board finds that hazards were identified, written documentation was in place, and workers were properly informed; however, the potential risk of the work to be performed was underestimated, leading to lapses in safety procedures and lack of appropriate controls.

Hazards were identified, but were underestimated by LLNL management and workers.

2.2.1.3 Develop and Implement Hazards Controls

Under this function, controls to prevent and/or mitigate hazards are identified and implemented. DOE Guiding Principle number 5, "Identification of safety standards and requirements," and number 6, "Hazard controls tailored to work being performed," form an important part of this process. The specific controls for a given hazard takes many forms, such as mechanical controls, administrative controls, and management controls. In this case, the hazards were to be controlled through the methods outlined in various documents, the Safety Analysis Report (SAR), the Facility Safety Procedures (FSP), the Health Physics Discipline Action Plan, and the OSP.

The safety envelope is described in the "Hazardous Waste Management Facilities Final Safety Analysis Report" (UCRL-CR-113523, dated July, 1996). The SAR covering B-513 included ten design considerations and administrative controls related to shredder operations and the waste to be shredded. It describes the minimal level of controls necessary for safe operations, but is not an operational level document.

The possibility that an Unreviewed Safety Question (USQ) could have existed was not examined by HWM. Because the SAR was written before the shredding operation had been fully defined, there was a possibility that a USQ could have existed. As described in DOE 5480.21, a safety evaluation is required for "temporary or permanent changes in the facility as described in the existing safety analyses." The Order defines the conditions that would result in a USQ. Based on this definition and the information obtained in interviews with the management, it seems likely that the safety evaluation may have determined that a USQ did not exist. However, failure to have made the safety evaluation is a violation of the USQ Order.

The possibility that an Unreviewed Safety Question (USQ) existed should have been examined.

The FSP describes the safety parameters for routine operations in this facility, the responsibilities and authorities of building personnel for assuring safe operations, and the controls for operational hazards and environmental concerns. Additionally, the FSP prescribes facility-specific training requirements, emergency controls, and maintenance and quality assurance requirements for environmental safety and health-related building systems. Any operation conducted in this facility that does not conform to the requirements and provisions in the LLNL Health and Safety Manual, the LLNL Environmental Manual, and this FSP must be supplemented by an approved OSP that specifically assesses responsibilities, hazards, and the controls necessary to conduct the operation safely. The FSP identifies the potential hazards and controls associated with hazardous, radioactive, and mixed waste for this facility.

LLNL Hazards Control had a Health Physics Discipline Action Plan in effect to monitor B-513 for contamination on a weekly and monthly basis. However, this plan was developed before shredder operations were considered and did not include any monitoring in the shredder room, or any routine inspection of the CAM. A draft revision to this Plan, which included monitoring of the shredder room, was being finalized at the time of the accident.

Hazards Control should not have allowed operations to begin without an Action Plan, and could have been more aggressive in assuring operations were conducted safely.

Operational Safety Procedures

Shredder usage is covered by LLNL OSP No. 514.7, dated February 15, 1997. The OSP specifies the safe operational procedures for the preparing and shredding of waste. It describes the work to be done, the responsibilities, the hazards, and corresponding controls.

An Operational Safety Procedure (OSP) dated February 15, 1997 covered the shredding of waste.

Notable safety features and administrative controls listed in the OSP include:

- A pre-operational inspection is performed daily.
- The unit is manned by two HWM personnel trained in its operation.
- Operations are monitored visually.
- An operational CAM and a portable radiation monitor are to be in the room when radioactive materials are processed.
- Electric interlocks are present and operational.
- Waste characteristics are verified prior to shredding to ensure compatibility between the equipment and the waste being processed.
- A HEPA filter equipped with a device to measure differential pressure across the HEPA filter is used to ensure that the filter performs as required.
- Maximum radioactivity contamination levels are restricted to 1 mCi of alpha and beta per 7.5 cubic feet of material.
- Flow rate across the hopper door to be an average of at least 125 linear feet per minute.

Several areas in the OSP relating to hazard control were found to be inadequate in ways that contributed to this accident.

Several deficiencies in the OSP contributed to the accident.

While the OSP describes the type of support from ES&H Team 4 that is required, no formalized process exists to ensure that these requirements are actually implemented or completed. The OSP specifies that Team 4:

- Must review and approve any changes in operations that increase the hazard level or introduces additional hazards; and
- Shall review waste disposal requisitions prior to shredding.

Team 4 only reviewed the waste requisitions for Campaigns 1 and 2; the required review for Campaign 3 was bypassed. Additionally, the issue of the CAM setup was not discovered until after the accident since there were no scheduled inspections for the CAM during this campaign.

The OSP requirement that only waste < 1 mCi per 7.5 cubic feet was to be shredded was included, but no information is given as to how this limit was to be documented through characterization or verified by the workers in the shredder room.

Radiation survey guidance in the OSP was inadequate. There was not a clearly stated requirement to survey incoming packages or wastes to evaluate radiation levels and/or surface contamination levels. The contamination survey was made even more necessary, given that the HEPA filters were being unwrapped prior to shredding. The requirement that the filters be unwrapped does not appear to have been well thought out, and was noted as a potential problem by the workers.

Two of the most important controls mentioned in the OSP are the CAM system and the respiratory protection program. These two controls are discussed in more detail below.

Continuous Air Monitoring System

The CAM was set to detect Pu-239 and Am-241.

Curium (Cm), plutonium (Pu) and americium (Am) each emit alpha particles with a characteristic energy. The detection window on a CAM is adjusted to only read alpha particles with the energy of the specific isotope of the element expected. The CAM providing coverage in the shredder room had been calibrated for Pu-239 and Am-241. The alpha particles from Cm-244 have a much higher energy than those from Pu and Am and, at low activities, would not normally be detected at this setting.

The alarm set-point for the CAM is normally determined by the Health Physicist appointed for the area. LLNLs Instrument Group indicated that their CAM calibration procedure calls for a set-point of 100 cpm, but that more than likely, they had set the set-point for this CAM at 25 cpm. The CAM and ALARM "on" indicators are provided by two function lights on the front panel. When activated, the alarm is by audible above ambient noise levels.

The CAM was moved into the shredder room sometime on March 7, 1997 (or shortly thereafter) for the first shredding campaign. The Hazards Control technician matrixed to the facility indicated that he had checked the CAM during Campaigns 1 and 2 and had probed (surveyed in-place) the CAMs filter paper with an alpha probe and detected no activity. The technician did note that after Campaign 2, one of the shredder operators had contacted him and sought his permission to move the CAM from its location in the shredder room. The shredder operator moved the CAM to a location some ten feet from the shredder.

Following the accident, a Hazards Control technician noted that the CAM was turned off and switched it on. The alarm was immediately activated by the radioactivity accumulated on the filter. A subsequent in-place evaluation of the CAM filter with an alpha probe indicated radioactivity levels in excess of approximately 20,000 cpm on the CAM filter and approximately 10,000 cpm on the surface of the CAM. Interviews with the shredder operators indicated that none of them knew how the CAM functioned or what the settings meant. They also indicated that they believed that the CAM was on because they could hear the air pump.

In summary, the CAM was not operating during Campaign 3. Whether it was ever on, or when and why it was turned off cannot be determined. Had the CAM been active during the shredder operation, the level of Cm-244 activity found on the filter paper would have been significant enough to cause the alarm to actuate despite being calibrated for the wrong radionuclides.

Even though the CAM was not calibrated for Cm-244, it would have alarmed had it been on.

Respirator Protection Program

Two of the individuals involved in the accident were contract employees covered under a separate respirator protection program. That program was not an issue in this accident, and therefore is not discussed. LLNL maintains an elaborate respiratory protection program that meets all applicable OSHA requirements, and American National Standards Institute guidelines. The program is managed by the Respirator Program Administrator, and is administered through various written procedures.

Each respirator user is required to be medically screened and fit-tested prior to obtaining a respirator. Fit-testing is conducted primarily by a quantitative method, which allows individuals to be tested under various rest and exercise conditions. LLNL requires a fit factor of ten times the manufacturer's suggested protection factor before an individual can be approved for use of a particular respirator. The fit-testing is repeated on an annual basis, or when there is a 10% change in the weight of the individual. Users are issued respirator specific ID cards following the completion of the required training and fit-testing.

Each respirator and each cartridge is tested by LLNL prior to issuance.

Each respirator is tested by the Respirator Services Group and each respirator cartridge is put through a monodisperse 0.3 micron Median Aerodynamic Diameter particulate size penetrometer test before being issued to a user. Respirators are issued in complete assemblies (cartridges are attached) to designated Issue Point Administrators, Supervisors, and Health & Safety Technicians for specific jobs for which a Hazards Assessment Document (HAD) has been provided to the Program Administrator. Multiple respirators may be issued for extended job coverage, but the storage and distribution location must be approved by the Program Administrator. Individual workers may directly obtain only one respirator from the Respirator Services Group during any given twenty-four hour period. The HAD normally stipulates the proposed work and expected hazards, and the administrative and personnel protective equipment required to mitigate the hazards.

The third campaign started sometime in June of 1997. No HAD was ever written for this activity, and since no respirators were issued by the Respirator Services Group to the operators or their supervisor beyond the last procurement (dated May 21, 1997), it is assumed that the use of the respirators with organic/HEPA cartridges was continued into Campaign 3.

2.2.1.4 Perform Work Within Controls

Readiness was not confirmed prior to beginning operations.

This function includes two activities, confirming that adequate preparation has been made prior to authorizing work and performing the work safely. There are a great many facts about the accident that confirms that neither of these activities was accomplished. Guiding principle number 7, "Operations authorization," emphasizes the importance of pre-start preparation. As no determination was made by the DOE Line Management that a Readiness Assessment was necessary, DOE Order 425.1 requires that the "contractor's standard procedures for startup or restart" be used. There is no indication that any standard procedures for startup had been established at the time of the shredder startup. As mentioned, a dry run was held to evaluate equipment performance, finalize safety procedures, and provide on-the-job training for the operators before beginning operations. No documentation was made of this important safety review process. Deficiencies noted during this time included air flow problems with the ventilation system. Modifications were made to correct these deficiencies, but no attempt was made to confirm these changes were effective. Readiness was not confirmed prior to beginning operations.

Once work begins, it must be performed safely, in accordance with safety controls.

Initially, the work appears to have been occurring as described in the

OSP. However, by the time of the accident, many of the important controls in the OSP were no longer in effect. Violations of the OSP include:

1. No portable radiation monitoring equipment in the shredder room.
2. No operating CAM.
3. Ventilation system < 125 lfm.
4. Activity limit of 1 mCi exceeded.
5. Tools (Sawzall) used inappropriately.
6. Hopper loading limit of one unit at a time exceeded.
7. No Hazards Control review of waste requisitions.

At the time of the accident, many of the important controls in the OSP were no longer in effect.

The Board finds that the work was not performed within the approved controls and this was a significant contributing factor to the accident.

2.2.1.5 Provide Feedback and Continuous Improvement

Continuous improvement is a process in which work processes and organizational performance is continuously measured and evaluated to identify improvement opportunities. Interviews with those involved indicate that, in this case, the shredding process may have had the opposite effect. The initial success of the first HEPA shredding campaign fostered complacency towards safety practices. Attention to safety controls, such as review processes and work restrictions, seems to have declined as the process continued. For example, modifications were not evaluated and information about the clogging of the pre-filter was not considered for its effect on the performance of the ventilation system.

The Board finds there was no continuous improvement process in effect.

2.2.2 Personnel Performance (Human Factors, Training, and Qualifications)

This section presents the various elements that affects an individual's performance, focusing on operability, work environment and management elements. The three primary factors are: 1) the individual's capability to perform, 2) equipment/machine errors, and 3) environment. Guiding principle number 3, "Competence commensurate with responsibilities," plays an important factor in insuring work is performed within controls. The equipment and machine errors are discussed throughout this report. The humidity and temperature on the day of the accident were relatively low for early July, and therefore the environment was not considered to have played a significant role in the accident.

2.2.2.1 Waste Generator

Individuals and management involved in B-251 waste characterization did not exhibit an appropriate level of capability based on their experience and knowledge in waste management. To adequately perform, the involved personnel must possess the experience, knowledge, skills, and abilities that are necessary to discharge their responsibilities. Based on interviews, the individual involved in filling out the requisition did not fully understand waste management practices and regulations or radiological science. Management did not understand that the generator is responsible for characterizing the waste. The importance of characterization to safety was not understood, nor was the importance of process knowledge to the characterization process.

Individuals and management involved in B-251 waste characterization did not exhibit an appropriate level of capability.

2.2.2.2 Hazardous Waste Management

Except in one area, HWM shredder operators appeared to have the experience, knowledge, skills, and abilities to discharge their responsibilities. The operators had taken the required training. Three of the four shredder workers in question received their on-the-job training during Campaign 1 which was formally documented. Worker 4 was receiving his official on-the-job training during the time of the accident. The AIB was told by the shredder operators that they assumed that the CAM was operational based on the sound of the CAM (i.e., the sound of the air pump). Workers could have been better trained in the operation of the CAM and in the importance of the CAM program for worker safety training.

Based on interviews with other shredder workers, Worker 1 did not exhibit any physical or mental impediments that could have affected his performance on the day of the incident, even though Worker 1 had been in the shredder room for approximately three hours.

2.2.3 Management Systems

As part of the accident investigation, the Board analyzed the LLNL management system and the DOE line management and oversight system for potential impacts. Generally, these systems exist, but problems were noted in the implementation of actions required.

2.2.3.1 LLNL Management Systems

LLNLs Health and Safety Manual contains a policy that addresses Integrated Safety Management. Section 1.8 of the LLNL Health and Safety Manual implements these core safety management functions in order to provide the necessary structure for any work activity at LLNL that could potentially affect the public, the workers, or the environment.

In addition, LLNL has an assurance system which focuses on quality assurance and compliance. Currently, the Quality Assurance Office within HWM provides information about operations but does not evaluate compliance with procedures. There are plans being made to expand this role to include evaluation of adherence to procedures. The Board believes this would be a useful addition.

The Board concluded that the LLNL management systems exist, but are deficient in their ability to assure hazards are adequately evaluated, operations are conducted within approved procedures, and information is appropriately shared by organizational elements. These deficiencies encompass the major contributing causes of the accident and support the Board's conclusions.

2.2.3.2 DOE Line Management and Oversight

DOE/OAK is the field organization responsible for operations at LLNL. Waste management activities at LLNL are conducted through the Office of the Associate Manager for Environmental Management and the Waste Management Division (WMD). In accordance with DOE Guiding Principle number 1, Program Managers and Facility Representatives/Facility Operations Engineers within each line program division are responsible for assuring that their respective programs are conducted within the confines of the program envelope. This is accomplished through two ways: through administrative controls (i.e., policies, procedures, and safety documents) and through operational awareness.

The primary administrative control for the shredder operation was the SAR for the facility. The OSP which covers the actual operation of the shredder is a contractor-generated document. The OSP is not approved by the DOE, but is reviewed as part of operational awareness. An approved SAR broadly describing the shredding process, design considerations, and administrative controls was in place at the time of the accident. Prior to approval, the SAR had been reviewed by DOE/OAK ES&H personnel outside the line program. The SAR did not specifically mention HEPA filters as material that would be shredded, referring instead to "solid mixed waste, such as debris and empty containers." The decision to include HEPA filters in the material to be shredded had not been finalized at the time the SAR was being prepared. Had HEPA filters been specifically

An approved Safety Analysis Report (SAR) broadly describing the shredding process, design considerations, and administrative controls was in place at the time of the accident.

mentioned in the document, the decision to shred them may have come under greater scrutiny by the reviewers. What changes, if any, would have resulted from this higher level of review is unclear. However, HEPA filters do fall within the definition of solid mixed waste found in the SAR. The Technical Safety Requirements (TSRs) for this facility were in draft form at the time of the accident, but none of the draft TSRs were directly related to the operation of the shredder.

The Board reviewed the requirements of DOE Order 425.1, "Startup and Restart of Nuclear Facilities" as they would apply to the accident. The startup of the shredding operation did not require a Operational Readiness Review (ORR), based on the conditions described in 425.1, paragraph 4.a.(1). When an ORR is not required for an operation startup, the Order states that DOE line management shall evaluate whether a Readiness Assessment (RA) should be made, even if the work is within the existing safety authorization basis documents. Given the absence of a USQ and the very low-levels of contamination expected in the material to be shredded, line management would likely have determined that an RA was not required. However, no record is available to show that an evaluation was officially made.

The second way in which DOE/OAK personnel can insure operations are conducted within the safety envelope is through on-site presence. At the time of the accident, the Waste Management Division (i.e., the line management) had an approved "Environment, Safety and Health Management Plan for Environmental Management Program Activities" in place. This plan describes the goals and requirements for conducting management reviews and surveillances and the responsibilities for program managers and facility representatives. ES&H personnel are available to assist these managers by providing multi-discipline expertise.

Walk-through requirements were generally being met.

Program managers are required to conduct, at a minimum, walk-throughs and surveillance of Area 514 once every two months (i.e., bi-monthly). A review of these documented surveillance records indicated the program manager and the assistant program manager noted various visual safety non-compliance activities (e.g., labeling, tripping hazards, and drum stacking requirements).

The facility representative is required to conduct walk-throughs and surveillance at a minimum of twice a month. The facility representative is WMDs point-of-contact for all ES&H matters.

Examples of assigned responsibilities include, but are not limited to, the following: keeping up-to-date on ES&H regulations regarding occupational health and safety, radiological protection, and nuclear safety; ensuring that all required hazard baseline documentation (e.g, Health and Safety Plans, Safety Analysis Reports, Technical safety Requirements) have been issued; and to identify ES&H deficiencies and coordinate with contractor management to resolve and correct the deficiencies in a timely manner. Records indicated that these walk-throughs/surveillance requirements were generally being met, but infrequently included OAK ES&H personnel.

The walk-through program does not include any requirements regarding participation or oversight of operations, including the start-up of new operations. Neither the program manager nor the facility representative participated in the initial dry run or witnessed the shredding operation first hand. LLNL has tried to minimize conducting operations such as shredding when DOE personnel were present due to safety concerns. In this case, the lapses in safety procedures appear to have begun during the 6 days of the third campaign, and not during the dry-run or Campaigns 1 or 2. In order to detect these safety lapses, walk-throughs of the general area of this facility would have had to have been occurring at least once a week. The facility representative would have had to observe the operation through the window of the personnel door, as he was not respirator qualified.

The Board concludes that there were no significant failures in the DOE oversight management function which directly contributed to the accident. However, the Board believes the Line Program walk-through requirements could be improved by including provisions requiring DOE presence for new or restarted operations, especially those with a high risk. A concerted effort should be made to include ES&H expertise in the walk-through and surveillance programs. In addition, where possible, walk-throughs should be timed so as to coincide with operations. Concerns about DOE personnel impacting operations safety are unfounded. All Line Managers have received the necessary training to safely walk-through the facilities at any time and understand which areas they may safely enter.

There were no significant failures in the DOE oversight management function which directly contributed to the accident; however, the DOE walk-through program could be improved.

2.3 Respirator Analysis

At the request of the AIB, all four respirators used by the shredder operators were recovered in the cold area of B-513. All four respirators were an Ultra-Twin full-face model (3 medium and 1 large), manufactured by MSA. Before being removed from the building, each respirator was bagged separately. Eight respirator cartridges were recovered from the 55-gallon drum used to store used anti-C clothing. Four of the filter cartridges were an organic/HEPA combination, two were an organic/acid/ammonia/HEPA combination, one was an organic/acid/HEPA combination, and one was mercury/HEPA. Seven of the eight filter cartridges were collected in one bag at the time of recovery.

The respirator and filter cartridges worn by Worker 1 were identified based on their levels of contamination. Immediately following the accident, a cursory exit survey of Worker 1's respirator and cartridges showed contamination levels in excess of 40,000 cpm. Respirators and cartridges worn by the other workers were significantly less contaminated. Worker 1 had indicated that he was wearing an organic/HEPA combination cartridge, but since there were two pairs of this type recovered, the only way to isolate his was to base it on the level of contamination. Worker 1 had done most of the shredding and cutting of HEPA filters on the morning of the accident.

Respirator Surveys

The workers respirators were recovered and surveyed.

On August 18, 1997, all four of the worker's respirators were surveyed to determine their contamination levels. The highest contamination was found on a medium sized respirator manufactured in July of 1990, and assumed to have been worn by Worker 1 (see Exhibit 2-7). For this respirator, 30,000 cpm were detected around the exterior of the exhalation valve, 30,000 cpm in between the left cartridge holder and the exhalation valve, 20,000 cpm over the voice box, 4,000 cpm around the left cartridge holder, some 3,000 to 4,000 cpm on the straps of the respirator, and 3,000 on the outer surface of the lens. Except for the area around the forehead seal (20,000 cpm), no contamination was detected on the interior (accessible areas) of the respirator using a Blue-Alpha meter.

Contamination levels on the remaining three respirators ranged from less than 1,000 cpm on the two medium sized masks, to up to 6,000 cpm on the large-sized respirator. No contamination was detected on the inside of these three respirators.

A more comprehensive survey of the respirator was conducted on August 20, 1997. Following the penetrometer tests, Worker 1's respirator was dismantled to obtain a comprehensive contamination profile. The survey was performed using a Blue-Alpha meter either directly, or by using a Q-tip to swab inaccessible areas.

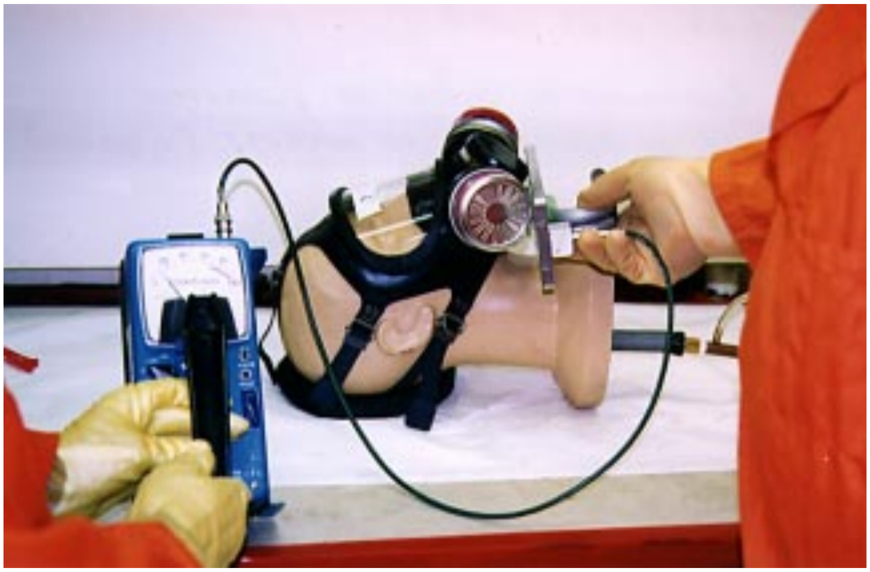

Exhibit 2-7: Photograph of Worker 1's Respirator during testing.

The contamination level on the plastic exhalation valve cover of Worker 1's respirator was found to be 30,000 cpm. The grooved area around the diaphragm indicated 10,000 to 12,000 cpm. The exterior side of the exhalation flapper valve indicated less than 1,000 cpm, while the interior surface indicated no contamination. An examination under a magnifying glass showed no evidence of cracks or objects that could have prevented the flapper valve from closing. The inside of the exhalation tunnel was swiped and no contamination was found.

The speaking diaphragm housing was removed and 3,500 cpm was found on the interior surface of the housing and on the plastic locking ring. The metal speaking diaphragm itself showed no contamination.

The interior surfaces of both cartridge holders were surveyed and swiped and no contamination was found. Swipes of the cartridge receptacle, sealing gasket and inhalation valve seats showed no contamination.

The inside chin area of the respirator indicated contamination levels of 1,000 to 1,500 cpm. 10,000 cpm was detected on the inside of the nose cup, in between the two valves or in the nose bridge. No contamination was found on the exterior surface of the nose cup. With the nose cup removed, the inside of the respirator showed contamination levels of around 3,000 cpm.

Survey of Respirator Cartridges

All eight cartridges were surveyed for contamination. Two were found to have contamination levels of 200,000 cpm each on the external (outer) surfaces. The inner surfaces (which fit into the filter receptacles) were below 1,000 cpm. Of the remaining cartridges, one had an external contamination level of 40,000 cpm, one at 10,000 cpm, and the rest were found to be below 700 cpm.

Quantitative Testing

Worker 1 was re-fitted on July 28, 1997 by LLNL Respirator Services personnel to see if there had been any significant facial changes since the last time he was fit tested (August 1996). The LLNL respirator fit test requires a fit factor of 1000, which is ten- times the manufacturer's standard. On the first try using the Ultra-Twin MSA full-face respirator, Worker 1 did not initially follow the step-by-step procedures recommended by LLNL for donning full-face respirators, and therefore failed to meet the fit factor requirement.

On the second test, his overall score was greater than 1000, indicating a successful test; however, on one segment he scored 369, which is judged as a "marginal pass" based on LLNL standards. On the third test, he scored an average fit-factor of greater than 1000.

Each of the four respirators was examined under a magnifying glass to look for cracks, tears, etc., since it is possible that the respirators had been reused over at least a two-day period of shredding operations. No cracks or tears were found. Each respirator was then fitted with new organic/HEPA cartridges and subjected to a quantitative protection test using ambient air particulate (0.6 to 0.8 micron) flow-through methods.

Following the accident, Worker 1 did not initially pass his respirator re-fit test.

Worker 1's respirator showed concentration levels averaging 0.4 particles per cubic centimeter of air, while the outside concentration was at 2,000 particles per cubic centimeter. These results would indicate that it was a successful test (the respirator performed as designed).

The two filter cartridges used by Worker 1 were also individually subjected to a similar test. The concentration passing through the cartridges was less than 0.6 particles per cubic centimeter, while the ambient concentration was at 4,000 particles per cubic centimeter. This result would indicate that the cartridges maintained their integrity and functioned as designed.

Post-accident testing indicated that both Worker 1's respirator and cartridges performed as designed.

Potential Inhalation Route

The contamination profile of Worker 1's face and head showed the highest contamination to be on the bottom of his chin (190,000 cpm). The next highest level was found under his right eye (70,000 cpm), followed by his nostrils at 8,000 to 10,000 cpm. The neck and head had only residual levels (< 2,000 cpm) of contamination. No contamination was found on his forehead or upper chin.

Poor fit could have caused the contamination to enter the respirator.

One possible scenario for the worker intake is for the contamination to have entered his respirator through a break in the seal at the bottom of the chin. The intake of his breath would have drawn the air around the bottom of the mask, up around his chin, past his moustache, and into his nose. This is consistent with the pattern of contamination on his face. Immediately after the accident, Worker 1 had reported feeling a breath of fresh air at one point during the shredder operation that morning.

The gap in the seal could have occurred as a result of a poor fit. This is supported by the failure of Worker 1 to pass his post-accident respirator fit test on the first attempt, followed by a marginal pass on the second attempt. Another possibility is that the lower straps of the mask became loose during the shredder operation. In the AIB interviews following the accident, Worker 3 described how the tape holding his anti-C suit to his respirator had once caught on the buckle of his respirator strap and had loosened it, allowing unfiltered air to enter his mask.

Contamination could have occurred during removal of the respirator.

An alternate inhalation route is that the intake occurred during the removal of Worker 1's anti-Cs and/or his respirator. A possible explanation is that in the process of Worker 1 removing his respirator, he inhaled re-suspended contamination from his respirator or coveralls. This theory would be supported by the fact that the responders received a slight internal uptake as well. The contamination in the nose cup could have come from grabbing the respirator to unscrew the filter cartridge.

The respirator could have been overwhelmed by the contaminated environment.

A third alternative inhalation route is that the protection capability of the respirator was overwhelmed by the concentration of airborne particles encountered during the sawing operation. Based on the contamination level on the Sawzall, it is possible the respirator was confronted with an environment that overwhelmed its protection factor. However, no pathway and no inside respirator contamination supported this specific route, therefore although this alternative is possible, the Board deemed it to be less probable than the other two.

The Board concluded that any of the three alternatives, or a combination of the three, were feasible. Therefore, the Board presents the direct cause of the accident as a failure of respiratory protection by an undetermined mechanism.

2.4 Barrier Analysis

A barrier is defined as anything that is used to control, prevent, or impede process or physical energy flows and that is intended to protect a person or object from hazards. The barrier analysis addressed three types of barriers associated with the accident: administrative barriers, management barriers, and physical barriers. The Barrier Analysis is provided as Table 2-1, while the Barrier Analysis Summary is provided as Table 2-2.

In performing the barrier analysis, the Board identified seven failures which could have resulted or contributed to Worker 1's intake. The barrier that was directly breached and resulted in the uptake was the failure of the respirator to provide necessary protection, which was probably caused by inappropriate wear or which could have been caused by improper removal.

Six barriers were breached that directly contributed to the intake. Physical barriers breached were the CAM alarm and shredder ventilation. Administrative barriers that failed were improper waste characterization, and safety procedures not followed. Supervisory and management barriers failed in the areas of internal communications, and in adequate supervision and management oversight.

The barrier analysis supported the Boards conclusions that the cause of the intake was the failure of managers and supervisors to adequately analyze, control, and manage the hazardous waste generation and treatment operations.

2.5 Change Analysis

A change analysis was conducted to determine changes or differences that may have contributed to the accident. The results are presented in Table 2-3. This analysis and the barrier analysis were used to develop the root cause and contributing causes to the accident.

The exact cause of the breach of the respiratory protection could not be determined.

2.6 Causal Factors Analysis

The Board determined the direct cause of the accident was the breach of respiratory protection, the exact cause of which could not be determined.

All three inhalation alternatives were deemed feasible.

Barrier Analysis					
Hazard	**Direct Barrier or Control Failure**	**Possible Contributing Factors to Barrier or Control Failures**	**Possible Causes of Failures**	**Loss or Potential Loss Event**	**Evaluation**
Inhalation of Airborne Radioactivity	Respiratory Protection	Doffing error Improper wear Protection overwhelmed	Operator error Excessive airborne concentration	Significant Internal Exposure	Exact mechanism undetermined
	CAM Alarm	CAM calibrated for different radionuclides because curium not expected CAM turned off	Poor waste characterization Health Physics Discipline Action Plan not updated for shredder operations		Air monitoring not implemented for shredding operations
	Shredder Ventilation	Shredder system not adequately designed for dusty operations, and added ventilation did not adequately control airborne contamination Clogged pre-filter reduced air flow	Decision to use equipment not based on risk analysis, best practices or adequate evaluation Safety system tests not performed after system modification Failure to recognize significance of clogging		Management and workers did not fully recognize the ventilation system as an important safety system
	Waste Characterization	Underqualified individuals filling out the requisition Generator did not characterize waste; used default value of low level of americium contamination (<1 µCi) HWM characterization inadequate	Generator practice changed and HEPA filters no longer characterized using gamma spectroscopy Characterization plan was inappropriate		Generator Facility management underestimated the importance of waste characterization to safety Characterization plan developed without adequate hazards awareness

Table 2-1: Barrier Analysis

Barrier Analysis (continued)					
Hazard	**Direct Barrier or Control Failure**	**Possible Contributing Factors to Barrier or Control Failures**	**Possible Causes of Failures**	**Loss or Potential Loss Event**	**Evaluation**
Inhalation of Airborne Radioactivity (continued)	Safety Procedures	Safety procedures did not adequately address operating practices, known characterization problems, and underestimated the hazards of shredding HEPA filters	HWM had an inadequate process for review and revision of procedures	Significant Internal Exposure (continued)	Results of Campaign 1 resulted in management and operator complacency regarding safety
		Procedures not followed	Human error		
		No safety meeting prior to Campaign 3 start-up			
		Inadequate training on how to check CAM alarm			
		Pre-filter not tested			
	Internal Communications	Corporate process knowledge was not sought nor provided	Lack of personal responsibility		Management did not adequately address the greater communication requirements
		Hazards Control not consulted prior to shredding of B-251 waste	Lack of system to assure that appropriate knowledge is shared, reviewed and approved as required		Formal documentation and sign-off of reviews was needed
		Knowledge that B-251 waste characterization activities were suspect was not utilized	Lack of proper documentation		

Table 2-1: Barrier Analysis

Barrier Analysis (continued)					
Hazard	**Direct Barrier or Control Failure**	**Possible Contributing Factors to Barrier or Control Failures**	**Possible Causes of Failures**	**Loss or Potential Loss Event**	**Evaluation**
Inhalation of Airborne Radioactivity (continued)	LLNL Supervision and Management	Management was not sufficiently involved in the operation Management failed to recognize the inherent danger of the operation, use available technical resources, and remain vigilant Generator Management did not adequately assure that qualified and trained individuals occupied key positions	Complacency derived from the successful completion of Campaign 1	Significant Internal Exposure (continued)	LLNL failed in its management responsibilities

Table 2-1: Barrier Analysis

AFFECTED INDIVIDUAL	SHREDDER OPERATOR
PHYSICAL BARRIERS	RESPIRATORY PROTECTION CAM ALARM SHREDDER VENTILATION
ADMINISTRATIVE BARRIERS	WASTE CHARACTERIZATION SAFETY PROCEDURES INTERNAL COMMUNICATIONS
SUPERVISORY / MANAGEMENT BARRIERS	LLNL SUPERVISION & MANAGEMENT

Table 2-2: Barrier Analysis Summary

CHANGE ANALYSIS		
PRIOR/IDEAL	**PRESENT CONDITION**	**DIFFERENCE / ANALYSIS**
Waste requisitions properly completed by generator.	Waste requisitions were not properly completed by generator because incorrect process knowledge was provided, no analyses were performed, and individuals were not properly trained.	Facility management appointed unqualified, inexperienced, and poorly trained individuals that provided improper waste characterization data, contributing to the accident.
All waste to be shredded will be characterized.	All waste that was shredded was not characterized.	Failure to characterize waste allowed mis-characterized waste to be shredded, causing the accident.
Hazards Control review all waste requisitions before Campaign 3 is started.	No Hazards Control review of requisitions prior to start of Campaign 3 as required by FSP/OSP.	Failure of HWM to request Team 4 and Hazards Control review requisitions as required by the FSP/OSP prior to shredding contributed to the accident.
FSP/OSP cover all operational activities and procedures would be followed.	FSP/OSP did not cover all operational activities and procedures were not followed.	The use of the Sawzall, the failure to conduct regular surveys, an inadequate pre-operations check, and the inability to verify the flow rate of the ventilation system contributed to the accident.
Properly designed, properly tested and adequately maintained ventilation system.	Poorly designed and inadequately tested ventilation system that received limited maintenance.	Low air flow resulting from inadequate design, no air flow testing after installation of pre-filter, and lack of pre-filter air flow instrumentation contributed to the accident.
CAM operational.	CAM was not on.	Operators erroneously believed that the CAM was on, but it wasn't, contributing to a significant delay in identifying airborne contamination, thereby increasing the exposure.
Respirator protection appropriate to the hazard and fully functional.	Individual inhaled radioactive contamination.	The direct cause of the accident was the breach of respiratory protection, the exact cause of which could not be determined.
Supervisor is informed, knowledgeable, and ensures operations conducted in accordance with safety procedures.	Supervisor failed to ensure operations were performed according to the OSP and failed to obtain Hazards Control and Team 4 review of the requisitions.	Because Supervisor failed to ensure operations were performed according to the OSP and failed to obtain Hazards Control review of the requisitions, this condition allowed the highly contaminated filters to be shredded, contributing to the accident.
Management appropriately informed and involved in decision making.	Management not appropriately informed and not fully involved in decision making.	Management was not aware that Glove Box filters were to be shredded, was not aware that pertinent reviews had not taken place, did not act upon recommendations to modify shredder ventilation system, and trusted that generators characterized their waste streams correctly, all of which contributed to the accident.
Hazards fully analyzed and hazards controls fully in place.	Hazards not fully analyzed and inadequate hazards controls in place.	Management underestimated the hazards associated with shredding and became complacent because of successful results of Campaign 1.

Table 2-3: Change Analysis

Contributing causes (causes that increased the likelihood of the intake without individually causing the intake, and that are important enough to warrant corrective action) to the intake are as follows:

Contributing causes were identified.

- Operating Safety Procedures (OSPs) were inadequate and not followed;
- Waste requisitions significantly mis-characterized the amount and type of radioactivity contained in the HEPA filter(s);
- The CAM was not on, and
- Communications within and between Laboratory organizations failed to deliver needed information regarding wastes and the hazards of the operations.

The root cause of intake (the fundamental cause that, if eliminated or modified, would prevent recurrence of this and similar intakes) was the failure of management and supervisors to adequately analyze, control and manage the hazardous waste treatment operation.

The root cause of the accident was the failure of management and supervisors to adequately analyze, control and manage the hazardous waste treatment operation.

Analysis of the root and contributing causes indicates that the origin of this intake began with the change in management and waste characterization methods which occurred in B-251, the Heavy Element Facility, before 1995, and continued through a series of missed opportunities to the date of the accident. Missed opportunities included: not fully analyzing hazards associated with shredding HEPA filters prior to embarking on a shredding program; having an inappropriately designed, not fully tested and poorly operating ventilation system; failing to recognize filter clogging as impacting ventilation, and thereby safety; not reviewing contents of the individual HEPAs prior to shredding; failing to follow Operating Safety Procedures; and having a CAM that was not turned on.

Many opportunities to prevent the accident were missed.

3 CONCLUSIONS AND JUDGMENTS OF NEED

Conclusions are a synopsis of those facts and analytical results that the Board considers especially 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 directed at guiding managers in developing follow-up actions. Table 3-1 summarizes the conclusions of the Board and judgments of need regarding managerial controls and safety measures necessary to prevent or mitigate the probability of a recurrence.

CONCLUSIONS AND JUDGMENTS OF NEED	
Conclusions	**Judgments of Need**
Hazardous Waste Management failed to properly analyze hazards associated with shredding waste and failed to establish appropriate systems, procedures and controls for defense in depth. -No hazards analysis was done for glove box filters. -Ventilation system was inadequate. -Pre-start was inadequate.	**LLNL/HWM should:** 1.1 Evaluate implementation of the Integrated Safety Management System (ISMS) for Hazardous Waste Management. 1.2 Establish procedures to ensure appropriate analysis and review are performed prior to start of new operations. 1.3 Ensure operations are fully analyzed and appropriately controlled, and continuously improved.
Hazardous Waste Management failed to provide adequate supervision and management oversight to ensure operations are conducted in accord with procedures. In addition, first-line supervisors and workers were not sufficiently knowledgeable of safety procedures.	**LLNL/HWM should:** 2.1 Improve enforcement of compliance with existing operating and safety procedures. 2.2 Increase supervision and management's involvement in surveillance and performance-based assessments of operations. 2.3 Ensure personnel are appropriately trained in the use of procedures, safety equipment and alarms.
B-251 waste generator failed to accurately characterize waste.	**LLNL Management should:** 3.1 Evaluate effectiveness of current waste characterization program. 3.2 Identify other waste characterization errors and determine corrective actions where appropriate.
LLNL failed to adequately share waste characterization and hazard knowledge between organizational components.	**LLNL Management should:** 4.1 Develop and implement mechanism to share waste characterization and hazard data. 4.2 Seek input from employees with historical knowledge of operations and deficiencies in documentation.

Table 3-1: Conclusions and Judgments of Need.

4 BOARD SIGNATURES

______________________________ Date: ________________

William E. Lambert
DOE Accident Investigation Board Chairperson
U.S. Department of Energy
Oakland Operations Office

______________________________ Date: ________________

Samuel D. Brinker
DOE Accident Investigation Board Member
U.S. Department of Energy
Oakland Operations Office

______________________________ Date: ________________

Edwin I. Njoku
DOE Accident Investigation Board Member
U.S. Department of Energy
Oakland Operations Office

______________________________ Date: ________________

Diana Ramirez
DOE Accident Investigation Board Member
U.S. Department of Energy
Oakland Operations Office

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5 BOARD MEMBERS, ADVISORS, AND STAFF

Chairperson	William E. Lambert, DOE/OAK
Member	Samuel D. Brinker, DOE/OAK
Member	Edwin I. Njoku, DOE/OAK
Member	Diana Ramirez, DOE/OAK
Technical Advisor	Bill McConachie, LLNL
Technical Advisor	Dave Myers, LLNL
Technical Advisor	Donna Sutherland, DOE/OAK
Legal Counsel	Andrea Blohm, DOE/OAK
Administrative Support	Laura Frost, Uribe & Associates for DOE/OAK
Administrative Support	Ana Maria Osario, DOE/OAK
Graphics Support	Brett Clark, LLNL
TeleVideo Support	Steve Johnson, LLNL

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Appendix A: Appointment and Extension Memorandums for Type B Accident Investigation

DOE F 1325.8 (12-84)

United States Government — Department of Energy

memorandum

DATE: JUL 03 1997

REPLY TO ATTN OF: Oakland Operations Office, (ESHD)

SUBJECT: Establishing an Oakland Operations Office Type B Accident Investigation Board

TO: William Lambert, FCFO&BM

I hereby establish a Type B Accident Investigation Board to investigate the accident which occurred at Lawrence Livermore National Laboratory on July 2, 1997. I have determined that this accident meets the requirements for a Type B accident investigation as stated in DOE Order 225.1, Accident Investigations.

I appoint William Lambert as the Accident Investigation Board Chairperson. The Board Members are Samuel Brinker, Edwin Njoku, and Diana Ramirez. The Board will be assisted by other OAK personnel as needed.

The scope of the Board's investigation will include, but is not limited to, identifying and analyzing all facts to determine the direct, contributing, and root causes of the accident, developing conclusions, and determining the judgements of need that, when implemented, should prevent the recurrence of the accident. The investigation will be conducted in accordance with DOE Order 225.1. Additionally, the Board 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 application of lessons learned from similar accidents within the Department, work planning, practices, and procedures.

The Board will provide my office with periodic reports on the status of the investigation. The periodic reports will not include any conclusions until an analysis of all of the causal factors has been completed. Draft copies of the investigation report will be submitted to Environment, Safety, and Health Division and LLNL for a factual accuracy review prior to finalizing the report.

The report should be provided to me for acceptance within thirty (30) days from the date of this memo. Discussion of the investigation and copies of the draft report will be controlled until I authorized the release of the final report.

for James M. Turner, Ph.D.
Manager

cc: James Davis, AMEM
James S. Hirahara, AMSM
Michael K. Hooper, AMNS
Phil Hill, WMD
Ray Corey, LSO
John Ahlquist, ESHD

bcc: Samuel Brinker, WMD
Edwin Njoku, ESHD
Diana Ramirez, ESHD

DOE F 1325.8 (8-89)

United States Government — **Department of Energy**

memorandum

DATE: AUG 0 4 1997

REPLY TO ATTN OF: Type B Accident Investigation Board Chairperson William Lambert

SUBJECT: Extension of Curium Intake by Shredder Operator Type B Accident Investigation Schedule

TO: James M. Turner, Ph.D.
Manager

Your memorandum, dated July 3, 1997 established the Type B Accident Investigation Board and requested that the investigation report be provided to you within 30 days from the date of the memorandum. I am requesting that the activities of the Accident Investigation Board be extended to August 29, 1997 based on the following facts.

The high levels of contamination within the shredder room, scene of the accident, required the Accident Investigation Board and LLNL to move carefully in securing the facility, preventing the spread of contamination, and recovering evidence. In addition, the levels of contamination found on the respirator has made the testing of the respirator more difficult and time consuming.

We are making good progress and have most of the information needed to prepare our report. We have prepared the events and causal factor analysis and the barrier analysis although those cannot be finally completed until the respirator test results are available. Our root cause analysis and judgements of need have not been prepared. Report preparation has begun but we will not be able to complete the report until the respirator test results are available. I currently expect to submit our report for your review on or before August 29, 1997.

If you have any questions please feel free to contact me at (510) 422-1138.

William Lambert

William Lambert
Chairperson
DOE Type B Accident Investigation

cc: A. Alm (EH-1), HQ
T. O'Toole (EH-1), HQ
M. Frei (EM-30), HQ