U.S. Department of Energy
Office of Health, Safety and Security

Accident Investigation Report

Plutonium Contamination in the Zero Power Physics Reactor Facility at the Idaho National Laboratory, November 8, 2011

January 2012

Disclaimer

This report is an independent product of the Accident Investigation Board appointed by Glenn S. Podonsky, Chief Health, Safety and Security Officer, Department of Energy (DOE) Office of Health, Safety and Security. The Board was appointed to perform an accident investigation and to prepare an investigation report in accordance with DOE Order 225.1B, *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.

Release Authorization

On November 10, 2011, an Accident Investigation Board was appointed to investigate the November 8, 2011, plutonium contamination in the Zero Power Physics Reactor (ZPPR) Facility at the Idaho National Laboratory. The Board's responsibilities have been completed with respect to this investigation. The analysis and the identification of the contributing causes, the root cause, and the Judgments of Need resulting from this investigation were performed in accordance with DOE Order 225.1B, *Accident Investigations*, dated March 4, 2011.

The report of the Accident Investigation Board has been accepted, and the authorization to release this report for general distribution has been granted.

Glenn S. Podonsky
Chief Health, Safety and Security Officer,
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Table of Contents

Figures

Tables

Acronyms

AC	Administrative Control
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory – West
BEA	Battelle Energy Alliance, LLC
BIO	Basis for Interim Operation
BOQ	Basic Operator Qualification
CAM	Continuous Air Monitor
CAP	Corrective Action Plan
CAS	Contractor Assurance System
CEDE	Committed Effective Dose Equivalent
CF	Core Function
CFA	Central Facilities Area
CFR	Code of Federal Regulations
cfm	cubic feet per minute
cm^2	centimeter squared
COA	Condition of Approval
cpm	counts per minute
CWI	CH2M*WG Idaho, LLC
DAC	Derived Air Concentration
DID	Defense in Depth
DOE	Department of Energy
DOE-ID	DOE Idaho Operations Office
dpm	disintegrations per minute
DSA	Documented Safety Analysis
DTPA	Pentetic Acid (diethylene triamine pentaacetic acid)
EAL	Emergency Action Level
EAM	Emergency Action Manager
EBR-II	Experimental Breeder Reactor – II
ECAR	Engineering Calculations and Analysis Report
ECC	Emergency Control Center
ED	Emergency Director
EOC	Emergency Operations Center
EPI	Emergency Plan Implementing (procedure)
ERO	Emergency Response Organization
ES&H	Environment, Safety and Health
FAS	Facility Area Supervisor
FMH	Fissile Material Handler
FMHS	Fissile Material Handler Supervisor
fpm	feet per minute
FR	Facility Representative

FSAR	Final Safety Analysis Report
GP	Guiding Principle
HEPA	High Efficiency Particulate Air
HFEF	Hot Fuel Examination Facility
HPI	Human Performance Improvement
HPT	Health Physics Technician
HSS	DOE Office of Health, Safety and Security
ICRP	International Commission on Radiation Protection
INL	Idaho National Laboratory
ISRC	Independent Safety Review Committee
JCO	Justification for Continued Operations
JON	Judgments of Need
LWP	Laboratory Work Procedure
MDO	Management Duty Officer
MFC	Materials and Fuels Complex
M&O	Management and Operating
MOX	Mixed Oxide
MST	Mountain Standard Time
NE	DOE Office of Nuclear Energy
NFM	Nuclear Facility Manager
NFO	Nuclear Facility Operator
OE	Operational Emergency
OI	Operating Instruction
OJT	On-the-Job Training
OP	Operator
OPIT	Operator in Training
ORPS	Occurrence Reporting and Processing System
PISA	Potential Inadequacy of the Safety Analysis
POW	Plan of the Week
PPE	Personal Protective Equipment
Pu	Plutonium
PWS	Process Work Sheet
RA	Radiation Area
REAC/TS	Radiation Emergency Assistance Center/Training Site
RWP	Radiation Work Permit
SER	Safety Evaluation Report
SG	Safeguards Personnel
sfpm	standard feet per minute
SOMD	Site Occupational Medical Director
SS	Shift Supervisor
SSC	Structures, Systems, and Components
TEV	Technical Evaluation Study
TPR	Technical Procedure

TSR	Technical Safety Requirement
USQ	Unreviewed Safety Question
UTC	Universal Time Coordinate
WBC	Whole Body Count
ZPPR	Zero Power Physics Reactor

Executive Summary

On November 8, 2011, workers at the Idaho National Laboratory (INL) Materials and Fuels Complex (MFC) Zero Power Physics Reactor (ZPPR) Facility were packaging plutonium (Pu) reactor fuel plates. Two of the fuel storage containers had atypical labels indicating potential abnormalities with the fuel plates located inside. Upon opening one of the storage containers, the workers discovered a Pu fuel plate wrapped in plastic and tape. When the workers attempted to remove the wrapping material, an uncontrolled release of radioactive contaminants occurred, resulting in the contamination of 16 workers and the facility. The Department of Energy (DOE) Office of Nuclear Energy, under the requirements of DOE Order 225.1B *Accident Investigations*, requested that the Office of Health, Safety and Security appoint an Accident Investigation Board (the Board) to determine the causes of the accident and identify actions to prevent recurrence. The Board was appointed on November 10, 2011, and submitted this final report on January 4, 2012.

The Board concluded that this accident was preventable and that, over time, a number of opportunities had been missed that could have prevented the accident. The Board analyzed information and events dating back to the 1972 ZPPR Facility final safety analysis report, as well as events as recent as the initial medical treatment of the contaminated workers on the day of the accident. The investigation addressed the impacts of organizational transitions; past processes and procedures used when ZPPR was in operation; the historical and current technical assumptions of the ZPPR safety basis; current work planning and control programs and procedures; and the emergency management and response programs and implementation. In addition, the Board evaluated the oversight and self-assessment systems used by DOE and by the management and operating contractor, Battelle Energy Alliance, LLC (BEA), at MFC over the past several years relative to work planning and control and radiological protection programs.

Between 2004 and 2005, MFC responsibility transferred from the Office of Science to the Office of Nuclear Energy and to a new contract with BEA. The Idaho Operations Office (DOE-ID) and BEA conducted comprehensive transition planning and vulnerability analysis. After identifying deficiencies in the existing safety basis, BEA established a multi-year plan to update the safety basis for all MFC facilities. At that time, the ZPPR Facility was not operating, and ultimately, based on potential hazards and perceived risk; BEA prioritized the upgrade of the ZPPR Facility safety basis below that of the other MFC facilities.

As called for in the multi-year plan to bring all MFC facilities into compliance, the basis for interim operation for ZPPR was updated annually. Multiple reviews of these annual updates by DOE-ID and BEA failed to identify the legacy deficiencies in the technical bases related to the assumed low probability of damaged Pu fuel plate cladding and associated defense-in-depth controls. Through a review of records, the Board found that the probability of encountering damaged Pu fuel plates is higher than expressed in the ZPPR safety basis. The inaccurate underlying assumptions supported the continued reliance on a confinement hood, rather than a glovebox, for fuel plate packaging operations. The Board concluded that the oversight roles and responsibilities of DOE-ID to conduct reviews of the technical assumptions in the safety basis were not well communicated, understood, and resourced as needed.

The Board found that during the same period when the annual safety basis updates were taking place, more information came to light concerning the likelihood of having damaged Pu fuel plates in storage. In 2009, the Chairman of the MFC Independent Safety Review Committee (ISRC) provided a white paper to MFC management outlining past personal experience with ZPPR Pu fuel plates and offered recommendations for safer handling practices. MFC management did not recognize the significance of this information, so no evaluation of the need for additional controls through the Potential Inadequacy of the Safety Analysis (PISA) review process was considered necessary. The white paper was presented again in 2010 to the new MFC Nuclear Operations Director, but again its significance was not recognized and no action was taken. The Board found that BEA's mechanisms for communicating ISRC findings and recommendations, as well as the understanding of the MFC ISRC Chairman's authority, need to be improved.

The Board also found that during the organizational transition, historical ZPPR work practices and information were lost; these could have been used to establish more effective work controls for handing Pu fuel plates. Before 1992, ZPPR operations followed specific procedures and practices for handling damaged fuel plates and placing them in the storage vault. The information was recorded in a Suspect Fuel Log, and the fuel containers were labeled. This information was not effectively transitioned into current work planning and operating procedures. On the day of the accident, the Suspect Fuel Log was in the ZPPR Facility, but its content and value were not known either by workers or by their immediate supervisors or manager.

The Board found weakness in the current work planning and control process with respect to Pu fuel handing and packaging. The work direction provided in the Process Work Sheet (PWS) was not covered by any of the more robust operating instructions that were referenced. As a result, some work steps lacked a corresponding hazard analysis or accompanying mitigation for the hazards associated with loading the material into containers. Additionally, although the storage vault continuous air monitor (CAM) alarmed in response to the event as designed, its placement was not optimal for the work being performed. The evaluation points and limiting conditions provided in the Radiation Work Permit (RWP) to minimize worker radiation exposure did not result in a stop work and re-evaluating the hazards when unanalyzed/unexpected hazards where encountered. The underlying problem is that BEA did not recognize the hazards associated with the possibility of releasing Pu material. None of the work planning addressed the radiological and engineered controls necessary for mitigating a potential release of airborne Pu.

The Board acknowledges that the work group appropriately stopped work when they first recognized the abnormal condition presented by the labels on the Pu fuel plate storage containers. However, the management systems governing stop work broke down when workers were directed to proceed and cut the plastic wrapping around the Pu fuel plate, thereby releasing the hazardous radiological contaminants. This management system did not require the immediate supervisor and the manager to call in other subject matter and facility expertise for consultation prior to approving work to continue. In addition, Pu awareness training has not been effective in giving workers a full appreciation of Pu hazards. This lack of awareness contributed to the workers delaying their evacuation for nearly four minutes until they heard the radiation alarm.

The Board found that elements of the emergency management and response program were not fully effective. The absence of a hazards analysis for this accident scenario hampered timely decision-making. An earlier activation of the emergency response organization would have supported a more coordinated and timely response. Not having analyzed this accident scenario also limited the effectiveness of the medical response and delayed the assessment of radioactive material intakes for use in internal dose assessments.

The Board evaluated the DOE-ID and BEA management assessment processes for the past few years relative to MFC work planning and control processes and radiological controls. The field oversight conducted by DOE-ID Facility Representative is appropriately balanced and has been effective in identifying weaknesses and communicating them to management. In addition, BEA has noticeably increased the number of its self-assessments. However, these reviews have been insufficient to identify and correct issues to significantly improve performance. To be effective, BEA needs to provide more mentoring and direction to the individuals who conduct these self-assessments.

The Office of Nuclear Energy is required to ensure that DOE-ID and BEA develop corrective action plans, approve those plans, and ensure that the actions are completed and effective in addressing the Judgments of Need (JONs) identified by the Accident Investigation Board. Given the insights gained during the investigation regarding the underlying deficiencies in the ZPPR safety basis and the loss of important historical information during the organizational transition, the Board recommends that the Office of Nuclear Energy consider directing an extent-of-condition review of all MFC facilities.

Table ES-1: Conclusions and Judgments of Need

Conclusion	Judgments of Need
Safety Basis	
The Board concluded that the DOE-ID and BEA oversight systems were not managed in such a way that they could readily identify and correct legacy deficiencies in the technical bases supporting the ZPPR safety basis. **[JON 1, JON 3]** The Board concluded that BEA failed to recognize the significance of and take appropriate action in response to available information regarding the material condition of Pu fuel plates. **[JON 1, JON 2]** The Board concluded that actual Pu fuel plate failures were not reviewed in the appropriate context to lead to changing the observed failure rate as stated in the safety basis. As a result, workers were at increased risk of exposure to uncontrolled radioactive material. **[JON 2]** The Board concluded that the ZPPR Facility safety basis does not quantify credit associated with the ZPPR Workroom South Hood for mitigating accidental releases of radioactive material, nor does it provide technical bases for qualifying the Workroom South Hood as a defense-in-depth SSC. **[JON 4]** The Board concluded that, though credited in the ZPPR safety basis for defense-in-depth, the ZPPR Workroom South Hood was not maintained in such a way to provide assurance of its performance or operability. **[JON 5]**	JON 1: BEA needs to validate the technical bases used to support the safety and design basis of the ZPPR Facility, including a reassessment of the likelihood, severity, and risk of accidents and the effectiveness of hazard controls. JON 2: BEA needs to evaluate and revise the PISA and unreviewed safety question (USQ) processes to ensure that they are implemented and applied by facility management when new information is discovered that affects the safety basis of nuclear facilities. JON 3: DOE-ID needs to utilize all necessary resources to confirm the validity of ZPPR Facility safety basis assumptions prior to the resumption of fuel handling other than for recovery from this accident. JON 4: BEA needs to provide technical justification to DOE-ID and receive approval prior to performing plutonium fuel handling operations outside of a glovebox. JON 5: BEA needs to ensure that their nuclear facility maintenance program maintains equipment as credited in the documented safety analyses.

Conclusion	Judgments of Need
Work Planning and Control	
The Board concluded that the use of a PWS for the packaging activity was not consistent with the BEA procedure development process as defined by LWP-21220. **[JON 6]** The Board concluded that the planning effort did not include a thorough review of available historical data to assist in the work planning process. **[JON 7]** The Board concluded that the evaluation points and limiting conditions developed by the As Low As Reasonably Achievable (ALARA) review and required by the RWP were insufficient to result in stopping work and re-evaluating the hazards when unanalyzed/unexpected hazards transpired. **[JON 8]** The Board concluded that although the Vault CAM alarmed in response to the event as designed, its placement, as determined in engineering evaluations, was not optimal for the work being performed in the Workroom hood. **[JON 9]**	JON 6: BEA needs to use LWP-21220 generated procedures instead of process worksheets to direct work. JON 7: BEA needs to strengthen execution of the work planning process to ensure that a thorough review of available historical resources and lessons learned is conducted in order to accurately determine the scope of work. JON 8: BEA needs to ensure that ALARA reviews and RWPs address actions to be taken when abnormal conditions are encountered. JON 9: BEA needs to evaluate its program for establishing the placement of air monitoring equipment to provide workers with early indication of a radiological hazard.
Execution of Work	
The Board concluded that the work group failed to realize that the additional steps to cut the wrapping material from the fuel plate were outside the boundaries of the RWP and should have resulted in stopping work. **[JON 10]** The Board concluded that the work group performed operations to cut the wrapping material from the fuel plate without an approved procedure step to direct the action. **[JON 10]** The Board concluded the training provided by MFC00027 and other training experiences did not inform the workers adequately to alert them to stop working when they encountered the abnormal condition of multiple wraps of plastic and red tape after opening the clamshell. **[JON 11]** The Board concluded that training of MFC employees was not effective in providing the workers with the knowledge needed to recognize that a visible quantity of Pu particulate represented a hazard warranting immediate evacuation. **[JON 11]** The Board concluded that Radiological Control personnel had inadequate training that did not allow them to evaluate facility radiation monitor data and did not ensure that they could communicate this information accurately. **[JON 12]**	JON 10: BEA needs to reinforce the expectation that if a procedure cannot be performed as written, work should stop. JON 11: BEA needs to provide comprehensive facility-specific plutonium hazards training that maintains the proficiency of all managers, supervisors, and workers in recognizing unique hazards associated with working with plutonium. JON 12: BEA needs to provide training to the radiological control personnel on evaluating facility radiation monitor data and communicating this information accurately.

Conclusion	Judgments of Need
DOE Oversight The Board concluded that DOE-ID's field oversight at MFC has been appropriately balanced and effective in identifying weaknesses in contractor performance and communicating them to management.	No JON needed.
BEA Oversight The Board concluded that although there has been a noticeable increase in the number of self-assessments conducted at MFC, they lack the quality and depth needed to consistently identify and correct issues that significantly improve performance. **[JON 13, JON 14]**	JON 13: BEA must apply a concerted effort in the planning for and field observance of work activities at MFC until measureable improvement is attained. JON 14: BEA needs to provide mentoring and direction for MFC personnel conducting oversight activities in the field to improve identification of deficiencies.
Emergency Management The Board concluded that the BEA emergency management program did not sufficiently coordinate a timely response to the ZPPR operational emergency. **[JON 15, JON 16]** The Board concluded that the amount of chelate kept on hand was not based on accident scenarios. **[JON 17]** The Board concluded that BEA does not have a process in place to promptly assess intakes of radioactive material for use in internal dose assessments and medical response to radiological emergencies. **[JON 18]** The Board concluded that BEA does not have an effective program for training cognizant personnel on certain radiological response activities (e.g., showering before special lung counts, nose blowing) and communicating radiological information (e.g., information concerning bioassay samples). **[JON 15, JON 18]**	JON 15: BEA needs to develop and implement training on radiological response, including drills, exercises, and evaluation of radiological consequences of accidents. JON 16: BEA needs to reassess the hazards assessments at the ZPPR Facility and incorporate the results into the emergency management program. JON 17: BEA needs to evaluate the adequacy of the local availability of chelating material at INL facilities. JON 18: BEA needs improve processes that are used to identify radiological source term information for use in evaluating and responding to radiological emergencies.

Direct, Root, and Contributing Causes

The Board determined that this accident was preventable.

The Board determined that the **direct cause** of the accident was the cutting and handling of the plastic wrapping around the Pu fuel plate, which released the Pu contaminants.

Root causes are the causal factor(s) that, if corrected, would prevent recurrence of the same (local) or similar (systemic) accidents. The Board determined that the **local root causes** were:

- BEA did not accurately analyze the Pu hazard in the safety basis and establish commensurate controls.
- The management system lacked requirements intended to influence the decision making of the NFM and SS, resulting in a single-point decision to cut the wrapping.

The Board determined the following **systemic root causes**:

- DOE-ID accepted the risk of known safety basis deficiencies and allowed continued operation of the ZPPR Facility within the framework of a multi-year safety basis upgrade plan without putting effective interim controls in place.
- BEA continued operation of the ZPPR Facility with known safety basis deficiencies and without adequately analyzing the hazard to the worker or establishing effective work control processes.

Contributing Causes

Contributing causes are events or conditions that collectively with other causes increased the likelihood of the accident but that individually did not cause the accident. The Board identified three contributing causes to this accident:

1. The organizational transition resulted in a loss of knowledge and past practices and records that indicated the conditions associated with the fuel plates.

2. Senior MFC management did not recognize the significance of information provided by the history of Pu fuel plate failures and by the MFC ISRC Chairman's white paper.

3. The PWS used to conduct the work did not contain directions governed by any of the referenced operating instructions, leading to the creation of work steps without an appropriate hazard analysis or accompanying means of mitigation.

1.0 Introduction

On November 8, 2011, workers at the Idaho National Laboratory (INL), Materials and Fuels Complex (MFC), Zero Power Physics Reactor (ZPPR) Facility were packaging plutonium (Pu) reactor fuel plates. Two of the fuel storage containers had atypical labels indicating potential abnormalities with the fuel plates located inside. Upon opening one of the storage containers, the workers discovered that a Pu fuel plate was wrapped in plastic and tape. When the workers attempted to remove the wrapping material, an uncontrolled release of radioactive contaminants occurred, resulting in the contamination of 16 workers and the facility.

The U.S. Department of Energy (DOE) Office of Nuclear Energy (NE), under the requirements of DOE Order 225.1B, *Accident Investigations*, requested that the Office of Health, Safety and Security (HSS) appoint an Accident Investigation Board (the Board) to determine the causes of the accident and to identify actions to prevent recurrence. The Board was appointed on November 10, 2011, and submitted this final report on January 4, 2012.

This section of the accident investigation report describes the site and facility background and mission, contractual relationships, and the scope, purpose, and methodology of the accident investigation. Section 2 presents the facts and analyses developed by the Board, and Section 3 summarizes the Board's conclusions and Judgments of Need regarding the accident. Board members' signatures and the participating Board members, advisors, and consultants are listed in Sections 4 and 5, respectively. Documentation of the Board's appointment and its various analyses is provided in Appendices A through F.

1.1. Background and Mission

1.1.1. Idaho National Laboratory

INL is an 890-square-mile complex located in the high desert of eastern Idaho (Figure 1-1). In operation since 1949, INL is a science-based, applied engineering national laboratory dedicated to supporting DOE missions in nuclear and energy research, science, and national defense. The U.S. government first used this site in the 1940s to test artillery. In 1949, the newly formed Atomic Energy Commission established the National Reactor Testing Station at the site, and in the 1970s, the site was designated a national laboratory. The INL mission is to ensure the nation's energy security with safe, competitive, and sustainable energy systems and unique national and homeland security capabilities.

Day-to-day operations at INL are conducted by the contractor, Battelle Energy Alliance, LLC (BEA). The three primary facility areas are the Advanced Test Reactor Complex, dedicated to research supporting DOE's missions in designing, testing, and proving new fuel and materials technologies; the Research and Education Campus, which focuses on science, technology, and education integration; and the MFC, which focuses on nuclear materials and processing technologies. The INL currently employs more than 4,000 people and has a significant economic impact on Idaho Falls and the surrounding communities.

1.1.2. Materials and Fuels Complex

Located 28 miles west of Idaho Falls, Idaho, the MFC supports important national goals in advanced nuclear energy technology research and development and other energy science initiatives as part of nuclear energy, defense, and environmental management programs. Before 2005, the MFC was operated by the University of Chicago and was known as Argonne National Laboratory – West (ANL-W). In 2005, BEA took over management and operating (M&O) responsibilities.

The MFC mission is to: (1) store DOE spent fuel and other nuclear materials; (2) support nuclear energy and nuclear fuel cycle research and development; (3) support fuel manufacturing and characterization of nuclear materials; and (4) support National Nuclear Security Administration and National Aeronautics and Space Administration missions. The ZPPR Facility is one of the areas included under the management of the MFC.

1.2. Zero Power Physics Reactor Facility Overview

The ZPPR Facility is located at the MFC and was originally named the Zero Power Plutonium Reactor. The ZPPR Facility was a low-power reactor used to mock up cores for experimental purposes. ANL-W operated the Reactor between 1969 and 1992, when it was placed in non-operational standby. In the years that followed, the reactor and auxiliary equipment were removed from the facility. Current nuclear materials activities at the ZPPR Facility include storage in the ZPPR Vault, handling for surveillance and inspection, and packaging for shipment in the ZPPR Workroom. DOE is determining how to disposition the Pu inventory, primarily in the form of ZPPR fuel plates, stored in the facility. Ongoing analyses at another national laboratory will determine whether the material can be used to fabricate mixed oxide (MOX) fuel.

The ZPPR Facility includes the ZPPR cell (Building776), ZPPR Vault/Workroom (Building 775), and the ZPPR Materials Control Building (Building 784), supported by the ZPPR Control Room (Building 774). Workers enter the ZPPR Facility to inspect and inventory special nuclear materials and to prepare legacy reactor fuel plates for transfer to other facilities.

1.3. Contractual Relationships

In 2004 and 2005, there were several significant changes to the responsible DOE program office and the operating contractor at INL. At this same time, the INL’s cleanup activities were moved to a separate contract, the Idaho Cleanup Project managed by CH2M*WG Idaho, LLC (CWI), a limited liability company made up of CH2M Hill and Washington Group International.

Until 2005, ANL-W was operated by the University of Chicago under contract with the DOE Chicago Field Office, with program oversight provided by the Argonne Site Office. DOE Idaho Operations Office (DOE-ID) assumed responsibility for ANL-W on October 1, 2004. On February 1, 2005, BEA took over operation of ANL-W from the University of Chicago, and the name was changed to the Materials and Fuels Complex.

The INL M&O contract between DOE and BEA is a cost plus award fee contract with a total value of approximately $8.5B, with total annual fee available at $18.7M. This contract included a five-year base period with the option to extend it for up to five additional years. On October 1, 2008, DOE decided to retain BEA for the duration of the ten-year contract, and BEA will continue as M&O contractor at the INL through September 30, 2014.

Key BEA mission areas include nuclear energy, national security, science and technology supporting primary missions, operation of the INL site facilities, and site support services for environmental cleanup activities.

Figure 1-1. Aerial View of the Materials and Fuels Complex at the Idaho National Laboratory

1.4. Accident Investigation Scope, Purpose and Methodology

The Board reviewed and analyzed the circumstances surrounding the accident to determine its cause and understand lessons learned to reduce the potential for recurrence of similar accidents. This analysis also included an assessment of potential deficiencies in safety management systems. In addition, the Board was requested to specifically identify all relevant facts, determine direct, contributing, and root causes of the event, develop conclusions, and identify Judgments of Need (JONs) to support the prevention of recurrence. The scope of the investigation also included DOE programs and oversight activities. The terminology used in DOE accident investigations is defined in Figure 1-2.

The Board conducted its investigation using the following methodology:

- Facts relevant to the accident were gathered through interviews, document and evidence reviews, and examination of physical evidence.
- Event and causal factor charting, barrier analysis, change analysis, and human performance improvement techniques were used to analyze the facts and identify the cause(s) of the accident.
- Based on the analysis of information gathered, JONs were developed for corrective actions to prevent recurrence.

Accident Investigation Terminology
A **causal factor** is an event or condition in the accident sequence that contributed to the unwanted result. There are three types of causal factors: direct cause(s), which is the immediate event(s) or condition(s) that caused the accident; root causes(s), which is the causal factor that, if corrected, would prevent recurrence of the accident; and the contributing causal factors, which are the causal factors that collectively with the other causes increase the likelihood of an accident, but that did not cause the accident. The **direct cause** of an accident is the immediate event(s) or condition(s) that caused the accident. **Root causes** are the causal factors that, if corrected, would prevent recurrence of the same or similar accidents. Root causes may be derived from or encompass several contributing causes. They are higher-order, fundamental causal factors that address classes of deficiencies, rather than single problems or faults. **Contributing causes** are events or conditions that collectively with other causes increased the likelihood of an accident but that individually did not cause the accident. Contributing causes may be longstanding conditions or a series of prior events that, alone, were not sufficient to cause the accident, but were necessary for it to occur. Contributing causes are the events and conditions that "set the stage" for the event and, if allowed to persist or recur, increase the probability of future events or accidents. **Event and causal factors analysis** includes charting, which depicts the logical sequence of events and conditions (causal factors that allowed the accident to occur), and the use of deductive reasoning to determine the events or conditions that contributed to the accident. **Barrier analysis** reviews the hazards, the targets (people or objects) of the hazards, and the controls or barriers that management systems put in place to separate the hazards from the targets. Barriers may be physical or administrative. **Change analysis** is a systematic approach that examines planned or unplanned changes in a system that caused the undesirable results related to the accident. **Human Performance Improvement (HPI) / Error precursor analysis** identifies the specific error precursors existing at the time of or prior to the accident. Error precursors are unfavorable factors or conditions embedded in the job environment that increase the chances of error during the performance of a specific task by a particular individual or group of individuals. Error precursors create an error-likely situation that typically exists when the demands of the task exceed the capabilities of the individual or when work conditions aggravate the limitations of human nature.

Figure 1-2. Accident Investigation Terminology

2.0 Facts and Event Analysis

2.1. Event Description and Chronology

On November 8, 2011, at approximately 1000 Mountain Standard Time (MST), workers in the ZPPR Facility were beginning work activities to package Pu fuel into "foodpack" containers for transport to another national laboratory. This activity was to be performed as part of an effort to support mixed oxide fuel research and development. The persons in the area were:

- Operators in Training (OPIT-1, -2, -3, and -4)
- Health Physics Technicians (HPT-1 and -2)
- Staff Specialist
- Shift Supervisor (SS)
- Safeguards Personnel (SG-1)
- Security Police Officers (SPO-1, -2, and -3)
- Operators (OP-1,-2, and -3)

The Nuclear Facility Manager (NFM) was not in the area but was consulted during the work. In addition, a third HPT, HPT-3, responded to the ZPPR Control Room after the Vault continuous air monitor (CAM) alarm and the evacuation of the Workroom.

During the planned fuel packaging operation, workers were instructed to open Pu ZPPR reactor fuel plate storage containers called "clamshells" after removing them from ZPPR Vault storage. After removing four clamshells from the Vault, but before bringing them into the ZPPR Workroom for the operation, the workers noted that two of the clamshells had atypical labels reading "*CAUTION: RADIOACTIVE MATERIAL*," indicating potential abnormalities with the fuel plates located inside. The immediate SS and the NFM for the work were consulted, and a decision was made to proceed with the packaging operation. The four clamshells were then taken to the ZPPR Workroom (Figure 2-1) and placed in the South Hood (Figure 2-2).

Upon opening the first clamshell, the workers discovered that the Pu fuel plate was wrapped in plastic and tape. While attempting to remove the wrapping material, at approximately 1104 MST, the workers experienced an uncontrolled release and subsequent spread of radioactive contaminants in the ZPPR Workroom. This release resulted in measurable levels of radioactive contamination to a total of 16 workers, as well as various facility structures, systems, and components (SSCs).

Following a continuous air monitor (CAM) alarm, all personnel in the ZPPR Workroom evacuated to the ZPPR Control Room through normal pathways. MFC management and emergency response personnel were notified and dispatched to the ZPPR Control Room, where they began to survey and decontaminate affected personnel. Contaminated personnel were then transported to Experimental Breeder Reactor (EBR)-II, the Central Facility Area (CFA) medical facility, and the Whole Body Count (WBC) facility for additional medical evaluation and treatment.

At 1558 MST, airborne surveys outside the building were negative, indicating that the radioactive contamination was contained within the ZPPR Facility.

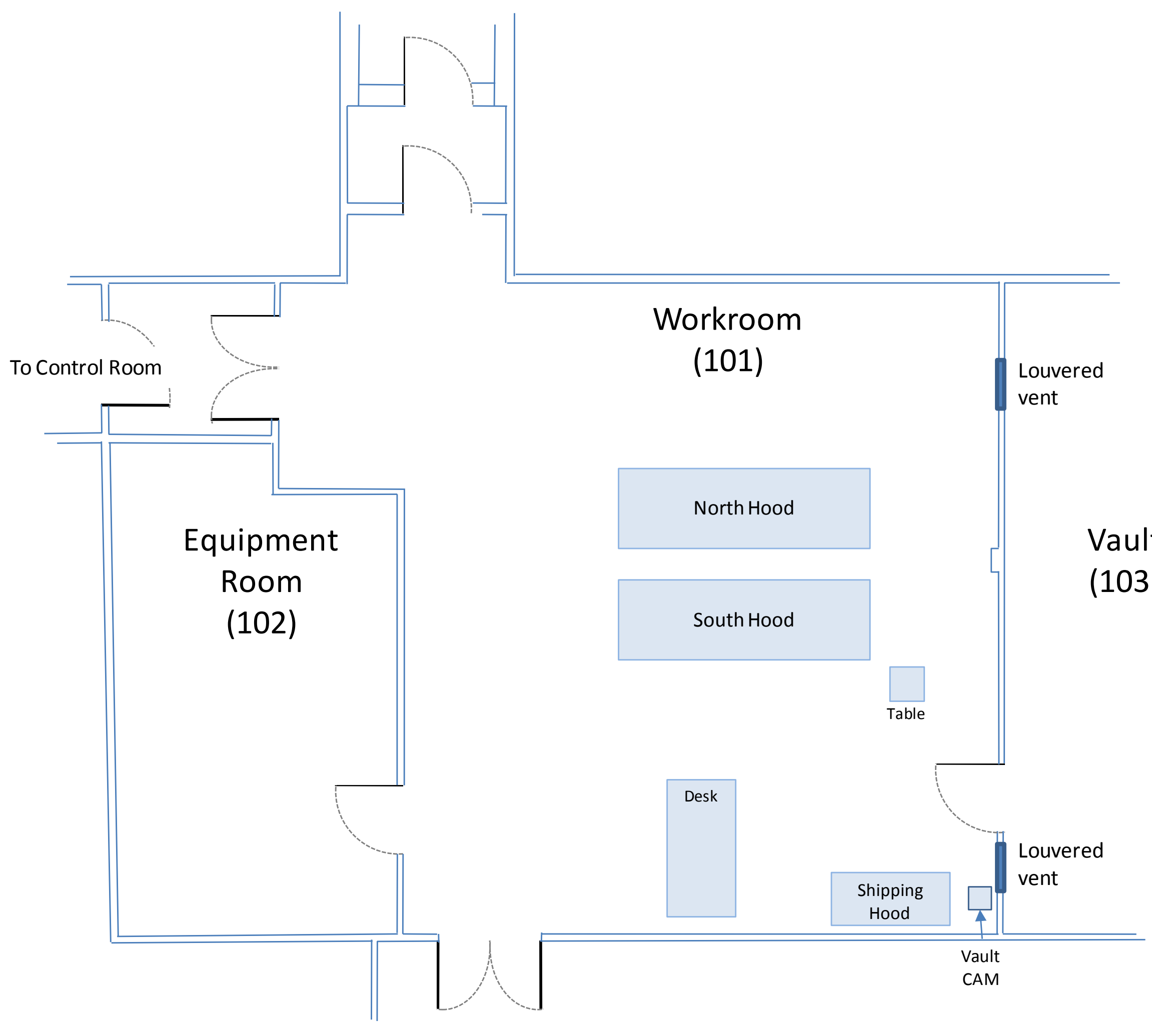


Figure 2-1. Diagram of ZPPR Workroom

Figure 2-2. ZPPR Workroom South Hood Area (circa 2008)

While developing timelines of the accident, the Board identified discrepancies in the available automated data. The work activities performed at the time of the accident were recorded on several video cameras, each with a "time stamp." The Vault CAM data was also recorded on an automated log. Comparison of an MST standard to the various recordings and logs revealed the following discrepancies:

- The clock on the Vault CAM showed a time that was 42 minutes and 8 seconds behind the MST. The Vault CAM data log header identified the time as Universal Time Coordinate (UTC), but was not set to UTC.
- Three videos showing the accident scene that were used for this investigation displayed times that were 58 minutes ahead of MST because it had not been changed from Mountain Daylight Time to MST and contained an additional two-minute time discrepancy.
- All other videos showing the accident scene displayed times that were 56 minutes ahead of MST for the same reasons as above.

In the chronology of events, Table 2-1, the time notations beginning on November 8, 2011, were adjusted to account for these discrepancies, using time offsets provided by BEA.

Table 2-1. Chronology of Events

Represents events directly related to work activities on November 8, 2011.

Represents the approximately four minutes from the release of contamination to the evacuation of the Workroom.

Date/Time	Event	Conditions
06/16/1972	"Defected ZPPR Fuel Plate 658-4006" was identified.	Referenced in Argonne National Laboratory (ANL), Materials Science Division memo, dated April 26, 1974.
03/05/1974	Failed ZPPR Fuel Plate Element #5-515-51, described "oil-canning" U-28Pu-2.5 Mo fuel element.	Discussed in ANL, Materials Science Division memo, dated April 26, 1974.
03/28/1974	"Failed ZPR Fuel Plate #3-F-372" was identified.	Referenced in ANL, Materials Science Division memo, dated April 26, 1974.
04/30/1981	Clamshell numbered 47 S was loaded with plate 802-21.	"Check Monthly" was written on the metal surface of the clamshell beneath the date.
07/15/1982	Clamshell numbered 45 M was labeled with a "CAUTION: RADIOACTIVE MATERIAL" label.	The label stated the following: **OPEN IN HOOD** **65 8" 042-41** **Swollen upper left corner near number** On 11/08/11, the plate inside was found to be wrapped in multiple layers of plastic and tape.

Date/Time	Event	Conditions
04/01/1986	Clamshell numbered 47 S is labeled with a “CAUTION: RADIOACTIVE MATERIAL” label. Clamshell was placed in the ZPPR Vault.	The label stated the following: **1-Plate Dented** **1-Plate <u>C</u> <10 d/m/plate α & is wrapped in plastic** Date of 03/31/86 on label was crossed out and it was re-dated with the 04/01/86 date. Writing on clamshell indicates that there were a total of three plates inside.
03/26/1991	Excessive Contamination Level was found on a PuAl fuel plate. (NE-CH-AA-ANLW-ZPPR-1991-0002)	Different fuel matrix than the 11/08/11 accident.
1992	The ZPPR Reactor was placed in non-operational standby.	
05/30/2003	ANL-W Deputy Associate Laboratory Director (ALD) issued a report on *Fissile Material Control Noncompliances of ZPPR*.	An independent investigation team determined the overall root cause of the noncompliances as “management deficiency.” Of specific note, the report expressed concerns with the lack of Pu-specific training and surveillance.
10/01/2004	MFC transitioned from Argonne Site Office to DOE-ID.	
01/14/2005	The ANL-W Deputy ALD commissioned Plutonium Operations Improvement Committee issued a final report.	The committee was chartered following contamination and uptake events. The review used DOE-STD-1128 as a reference. The report provided 13 recommendations, several which are relevant to this accident. Corrective actions were requested, but not implemented.

Date/Time	Event	Conditions
2005	DOE-ID and BEA conducted Nuclear Safety document reviews.	The reviews indicated that the state of ANL-W Nuclear Safety documentation at several MFC facilities, including ZPPR, did not fully satisfy the requirements of 10 CFR 830, Subpart B.
02/01/2005	MFC contract transition from ANL to BEA was completed.	
06/05/2005	ZPPR Basis for Interim Operation (BIO), DSA-006-ZPPR, Rev 0, was approved by DOE-ID.	Pu fuel plate failure identified as $2x10^{-5}$ (Extremely Unlikely).
December 2006	DOE-ID began a focused review of all MFC facility safety basis documents.	MFC facility safety basis upgrades were prioritized and scheduled for completion.
01/26/2009	The MFC Independent Safety Review Committee (ISRC) Chairman shared a white paper with MFC management to express concerns with the storage and handling of Pu fuel plates.	The paper outlined past experience with ZPPR Pu fuel plates and offered recommendations for safer handling practices. No action was taken to address these recommendations.
~ May 2010	Pu packaging activities began.	Work was performed in hood.
06/16/2010	ZPPR BIO, DSA-006-ZPPR, Rev. 7, became effective.	Assesses corroded/failed Pu fuel plate as "Extremely Unlikely." Reactor was removed from the Safety Basis.
2010	The ZPPR Reactor was dissembled and removed from the facility.	
12/20/2010	CAM alarm from contamination release while performing modifications on glovebox.	Led to a DOE “For Cause” review.
01/11/2011 to 01/13/2011	DOE-ID For Cause Review was conducted.	Review was in response to a finding of poor work controls involving radiological work practices at MFC. As a result, a portion of the contract award fee was withheld ($250,000).
03/17/2011	Category "R" Occurrence Reporting and Processing System (ORPS) report was issued with reference to radiological events.	Based on six ORPS and 14 non-ORPS issues since April 2009.

Date/Time	Event	Conditions
05/31/2011	NE approved transfer of Pu fuel plates from MFC. This is the work activity associated with the accident of November 8, 2011.	The transfer was part of a research project for MOX fuel.
06/23/2011	MFC Nuclear Operations Director was informed of MFC ISRC Chairman white paper.	The newly appointed MFC Nuclear Operations Director is briefed by the MFC ISRC Chairman related to the condition of the stored ZPPR Pu fuel plates.
07/25/2011 to 07/28/2011	DOE HSS radiological program review was performed.	Review was requested in response to NE concerns.
08/20/2011 to 09/05/2011	DOE-ID follow-up For Cause Review, Assessment of the Effectiveness of Improvements and Corrective Actions for BEA Work Controls and RAD Protection Programs, was performed.	Following the assessment DOE-ID elected to make the withholding of fee permanent.
09/01/2011	For the work conducted on November 8, 2011, the MFC received request for Pu fuel plates.	Eight plates of ID# 95 and 25 plates of ID# 146 0r 144 were requested.
10/05/2011	ORPS reportable Management Concern due to elevated dose identified on Extremity dosimetry at Hot Fuel Examination Facility (HFEF).	The “as low as reasonably achievable” (ALARA) beta limit was not incorporated into the radiation work permit (RWP) and work continued after a meter read off scale.
10/08/2011	BEA stopped all work at MFC requiring extremity monitoring.	Stop work was in response to the extremity exposure event reported on 10/05/11. Work was resumed following review, revising if necessary and re-activation of RWP.
11/02/2011	The ALARA Review (ZPPR-2011-003) is developed for fuel packaging operation.	
11/03/2011	Process Work Sheet (PWS)-34 for fuel packaging approved.	Approved by NFM, 11/03/11 Effective Date: 11/10/11 Work was performed before effective date of PWS.

Date/Time	Event	Conditions
11/03/2011	The RWP is approved for fuel packaging (MFC2011415/ZPPR-2011-003).	
From this point forward, the time used on the timeline was adjusted to MST, using time offsets verified by BEA.		
11/08/2011 0830	Pre-job briefing was given by OPIT-4 and HPT-2.	The briefing lasted about an hour and considered the response to several "what if" situations.
11/08/2011 ~0945	Workers entered the ZPPR Workroom and Vault.	
11/08/2011 0955	ZPPR Facility ventilation system was placed in Operate Mode.	
11/08/2011 ~0955 -1039	Workers placed four clamshells on two separate clamshell carts in Vault.	
11/08/2011 1039	SS directed clamshells to be moved to Workroom.	SS not logged into the RWP for packaging task.
11/08/11 ~1040	SS informed of labels on two of the clamshells.	Two of the clamshells have **“CAUTION: RADIOACTIVE MATERIAL” labels.** **The clamshell 45 M label states:** **OPEN IN HOOD** **65 8” 042-41** **Swollen upper left corner near number** The clamshell 47 S label states: **1-Plate Dented** **1-Plate C <10 d/m/plate α** **& is wrapped in plastic**
11/08/2011 1049	SS made phone call to NFM to discuss labels (abnormal condition).	NFM gave approval to proceed with packaging operation.
11/08/2011 1051	SS spoke to workers after call.	The SS informed workers of the decision to proceed.

Date/Time	Event	Conditions
11/08/2011 1052	SS briefly spoke to HPT-1.	This was a discussion on the decision to proceed; HPT-1 asks for verification of NFM decision.
11/08/2011 1053	HPT-2 surveyed clamshells.	No contamination detected.
11/08/2011 1054	HPT-1 moved portable air sampler into position next to hood.	Air sampler not positioned in breathing zone.
11/08/2011 1059	SG-1 removed Tamper Indication Devices from clamshells.	
11/08/2011 1100	Workers placed four clamshells into Workroom South Hood.	
11/08/2011 1100	HPT-1 surveyed clamshell carts.	No contamination detected.
11/08/2011 1101	OP-1 opened clamshell 45 M.	The clamshell 45 M label states: **OPEN IN HOOD** **65 8” 042-41** **Swollen upper left corner near number** Fuel plate observed wrapped in plastic and tape.
11/08/2011 1101	OP-1 handed smear of clamshell interior to HPT-2 while in the hood.	HPT-2 was not wearing proper personal protective equipment (PPE) for reaching into the hood.
11/08/2011 1102	HPT-2 returned with survey results of clamshell interior.	No contamination detected.
11/08/11 1102	An operator recalled questioning what to do in the event of a fire or finding a powder.	An operator recalled that the SS responded, “not a valid question.” The SS did not recall the conversation.

Date/Time	Event	Conditions
11/08/2011 1103	OPIT-3 and OP-2 passed cutting tool to OP-1.	The route used to pass the tool was inside the hood from one end to the other. HPT-1 frisked Operator in Training-3 out of the hood. While waiting for the cutting tool, OP-1 tried to feel for "dent" through the multiple layers of plastic wrap wearing two pair of gloves.
11/08/2011 1104	OP-1 cut though plastic wrap on one side of the plate and turns the plate over to cut the other side.	As reported in the critique, "many, many layers" of plastic were observed. Testimony indicated that the plastic was also wrapped in electrical tape. Black powder was noticed falling from plastic wrapping.
	UNCONTROLLED RELEASE OF RADIOACTIVE MATERIAL IN THE ZPPR WORKROOM.	
11/08/2011 1104	Workers crowded around the Hood in the vicinity of OP-1 and the open clamshell.	
11/08/2011 1105	OP-1 took a smear in the clamshell in the vicinity of the spilled powder.	OP-1 placed smear into "smear packet."
11/08/2011 1105	HPT-2 received smear in from OP-1 in smear packet.	
11/08/2011 1105	HPT-1 received smear packet from HPT-2 in a "terry towel."	The smear packet was wrapped in the terry towel.
11/08/2011 1105	HPT-1 prepared to count the smear in the scalar counter.	HPT-1 opened the smear packet and saw particulate, and then decided to not use the scalar counter.

Date/Time	Event	Conditions
11/08/2011 1105	HPT-2 retrieved alpha meter from table to survey smear.	Alpha meter "pegged." Meter was on 0.1 cpm scale. HPT-1 disposed of smear in the radioactive waste disposal receptacle trash. On 12/08/11, as part of the facility re-entry and evidence collection, the smear was evaluated. The event smear measured 5,500,000 dpm/100 $cm^2\alpha$ on 12/08/11.
11/08/2011 1106	SS gave a hand signal indicating a decision to cease the work evolution.	
11/08/2011 1106	The Hand and Foot monitor, located at the west end of the Workroom Hood, alarmed (“trouble alarm”).	SS, HPT-1, and HPT-2 go to monitor to investigate. Hand and Foot monitor was marked as out of order and was known to experience trouble alarms.
11/08/2011 1107	OP-1 removed outer gloves and placed them in bag.	OP-1 appeared to shake the bag that gloves were placed into.
11/08/2011 1107	Vault CAM alarmed.	Vault CAM fast response alarms at 500 DAC.
11/08/2011 1107	Workers began to evacuate the Workroom.	
11/08/2011 1108	HPT-1 returned to OP-1 and started bagging OP-1's hands to get him out of the South Hood.	
11/08/2011 1108	SG-1 returned to close and lock Vault door.	
11/08/2011 1112	Vault CAM readings continued to rise.	Vault CAM fast response peaked at 1906 DAC.
11/08/2011 ~11:35	Radiation Control personnel from other MFC facilities responded to ZPPR to assist with decontamination and transport six contaminated personnel to Experimental Breeder Reactor (EBR)-II.	

2.2. Event Categorization and Reporting

The Occurrence Reporting and Processing System (ORPS) report for this event (NE-ID--BEA-ZPPR-2011-0001) was categorized on November 8, 2011, at 1300 MST as a 1(1) Operational Emergency, "An Operational Emergency not needing further classification," as defined in Chapter 5, Paragraph 12 of DOE Order 151.1C, C*omprehensive Emergency Management System*, dated November 2, 2005. The DOE Headquarters Operations Center was notified on November 10, 2011, at 0858 MST, and the initial notification report was filed on the same day at 1121 Eastern Standard Time. Additional reporting criteria included:

- Group 4B(4) – Any facility evacuation, not including a precautionary evacuation, in response to an actual event. If the event fell under another reporting criterion, then evacuation should be reported as well by noting multiple reporting criteria for the single occurrence.
- 6B(3) – Identification of onsite radioactive contamination greater than ten times the total contamination values in 10 CFR 835, Appendix D, and that is found outside the following locations: Contamination Areas, High Contamination Areas, Airborne Radioactivity Areas, Radiological Buffer Areas, and areas controlled in accordance with 10 CFR 835.1102(c). For tritium, the reporting threshold is ten times the removable contamination values in 10 CFR Part 835, Appendix D.
- 6D(3) – Any onsite contamination of personnel or clothing (excluding site-provided protective clothing) that exceeds ten times the values for total contamination identified in 10 CFR 835, Appendix D. The contamination level must be based on direct measurement and not averaged over any area. This criterion does not apply to tritium contamination.

The ORPS report met the requirements of DOE Manual 231.1-2, *Occurrence Reporting and Processing of Operations Information.* BEA's immediate actions were included in the occurrence report.

See Section 2.4.5, *Emergency Management and Response*, for additional information on the Operational Emergency categorization/classification of the accident.

2.3. Initial Actions and Collection of Evidence

2.3.1. Scene Preservation

Following the local evacuation, the facility was sealed off to prevent the spread of contamination. BEA assembled a corporate investigation team to investigate the accident. Prior to and upon arrival at INL, the Board coordinated investigative efforts with DOE-ID and the BEA team to ensure preservation of the scene.

2.3.2. Collection of Evidence

BEA assembled a corporate investigation team within a day of the accident. Before arriving at INL, the Board established contact and coordinated initial investigative efforts with DOE-ID and the BEA team. In addition to preserving the scene, this coordination promoted control of evidence of interest to both parties, collection of the best available information, understanding of the facility's status, and identification of potential health and safety risks.

Documentation, combined with oral interviews, provided the Board with valuable information pertaining to facility safety bases, work control, other management systems, and safety practices that were in place at the time of the accident. Interviews with personnel also provided a detailed description of the ZPPR Facility's design, operation, and activities on the day of the accident, including the emergency response.

In addition, the Board examined physical evidence that was directly related to the accident – in particular, videotapes provided by the site. Using these recordings, the Board was afforded a unique opportunity to observe the entire work process taking place at the time of the accident.

Due to the levels of contamination expected in the ZPPR Workroom and the methods that had been used to isolate the Workroom and ZPPR Facility, a controlled re-entry to the Facility was needed to allow further collection of evidence (Figure 2-3). The re-entry, overseen by DOE-ID and executed by BEA, was conducted in phases in order to ensure a safe approach for assessing the facility condition. The removal and examination of evidence at the scene were synchronized with re-entry phases.

Figure 2-3. Re-Entry Activities Supporting Collection of Evidence

2.4. Examination of Evidence

2.4.1. Plutonium Fuel Plate Source Term

The Board determined that the radioactivity released in this event originated from a damaged rectangular fuel element constructed of a plutonium-uranium-molybdenum (Pu-U-Mo) metal alloy, which was clad in a stainless steel jacket, and then referred to as a fuel plate. Plutonium fuel plates of this particular construction were given the identification symbol "PUMN" and an identification number "95." Plates with this identification were manufactured by "Vendor 65." Relative to radionuclides important to dose and the mechanism for this uncontrolled release and dispersion of airborne radioactivity, the isotopic inventory associated with the fuel plate involved in this accident is shown in Table 2-2.

It should be noted that based upon interview testimony and conservative assumptions, it is postulated that less than 1% of the available material was released during the event.

Table 2-2. Isotopic Inventory Associated with the Pu Fuel Plate

	Pu-238	Pu-239	Pu-240	Pu-241	Am-241[3]	U-238
Decay Constant (yrs^{-1})	7.90E-03	2.87E-05	1.06E-04	4.81E-02	1.60E-03	1.55E-10
Half Life (yrs)	8.77E+01	2.41E+04	6.54E+03	1.44E+01	4.33E+02	4.47E+09
Specific Activity (Ci/gm)	1.70E+01	6.20E-02	2.30E-01	1.10E+02	3.20E+00	3.30E-07
Type M DCF (rem/Ci)[1]	1.10E+08	1.20E+08	1.20E+08	2.20E+06	1.00E+08	5.90E+06
Type S DCF (rem/Ci)[1]	4.10E+07	3.10E+07	3.10E+07	3.10E+05	1.00E+08	2.10E+07
July 1, 1983 Isotopic Mass (gm)	0.14	220.09	29.28	3.05	1.50	622.62
Current Isotopic Mass (gm)[2]	0.11	219.91	29.19	0.78	3.70	622.62
July 1, 1983 Isotopic Activity (Ci)	2.3188	13.6456	6.7342	335.0930	4.8070	0.0002
Percent of Mass	0.0%	25.0%	3.3%	0.1%	0.4%	70.9%
Percent of Activity	2%	11%	6%	72%	10%	0%
Type M - Percent of Dose	5%	41%	20%	5%	29%	0%
Type S - Percent of Dose	4%	22%	11%	1%	62%	0%

[1] WB (whole body); DCF (dose conversion factor). The Type M and Type S forms of the transuranics are assumed here because oxides are known to be virtually insoluble, and thus likely characterized by slow (S) or moderate (M) absorption in the body. Nitrate forms of these transuranics would likely be highly soluble and of Type F (fast absorbing). The reference for these values is International Commission on Radiological Protection (ICRP) 78.

[2] The time of decay is based on the fuel plate mass characteristics from the assay performed on July 1, 1983, until the day of the event, November 8, 2011. This time was approximately 28.3 years.

[3] For simplicity, this calculation conservatively assumes all decayed Pu-241 transmutates directly to Am-241, without decay. Type M DCF is used for all calculations.

Originally, intact fuel plates of this design were used in the ZPPR Reactor. Until the day of this accident, the damaged fuel plate in question was stored in the ZPPR Vault along with many other plates that were used during the 22 year operating campaign of the Reactor. A storage vessel, referred to as a "clamshell" (see Figure 2-4), was used to contain this fuel plate while in the Vault. Clamshells were originally intended for protection and transport of fuel plates throughout the ZPPR Facility, including from the Vault to the Workroom, and from the Workroom to the Reactor.

Figure 2-4: Clamshell with Fuel Plate

Analysis

By examining witness testimony and historic documentation, including the ZPPR Suspect Fuel Log, the Board determined that the fuel plate was damaged prior to being stored over 30 years ago. This damage resulted in a breach of the stainless steel jacket, which in turn allowed air (oxygen) and moisture (water) to infiltrate the fuel plate and react with the transuranic alloy. This assumption is supported the ZPPR Suspect Fuel Plate Log and by labeling seen on the clamshell that contained this fuel element prior to the accident, as well as witness testimony concerning the material condition observed during the accident. Over time, well-understood reactions between the air and moisture, which was present in the clamshell, and the metallic fuel alloy formed transuranic oxides and hydrides – likely including (but not limited to) UO_2, PuO_2, AmO_2, PuH_3, and AmH_3. For example, assuming Pu is the radionuclide, the formation of such compounds can generally be characterized by the following equations:

$$Pu + H_2 \rightarrow PuH_2$$

$$Pu + 2H_2O \rightarrow PuO_2 + 2H_2$$

These oxide and hydride compounds have far different physical properties than any of their constituents (i.e., transuranics, hydrogen, and oxygen); this fact is important in understanding this accident, since these new compounds readily form aerosols that are easily dispersible. During the fuel packaging operation in the ZPPR Workroom on November 8, 2011, these compounds were liberated, thus resulting in the accidental uncontrolled release of radioactivity.

The released aerosols would have likely been distributed throughout the Workroom over time, before settling, due to the natural circulation of air; however, this distribution by natural processes may have been accelerated by a number of mechanical factors. For example, after the material was spilled, a smear sample was taken within the clamshell, and then the clamshell was quickly closed, as observed in the video evidence. The act of quickly closing the clamshell lid over its base would have created a moderate overpressure and turbulence in the clamshell, thereby forcing air, and any aerosols entrained in that air, out of the space in which it was previously confined. The Board confirmed this theory as a mechanism for accelerating aerosol dispersion by using a clamshell provided as evidence. In addition, both before and after the clamshell closure, air turbulence associated with the operation of the hood, airflow from the open ZPPR Vault, and other factors may have contributed to the distribution of aerosols throughout the Workroom. Hood characteristics are further discussed in Section 2.4.2.4.

2.4.2. Safety Basis

For a Category 3 nuclear facility, such as ZPPR, the safety basis consists of all documented safety analyses (DSAs) and hazard controls, which provide reasonable assurance that the facility can be operated safely in a manner that adequately protects workers, the public, and the environment. For ZPPR, the safety basis is captured and documented in its current basis for interim operation (BIO), DSA-006-ZPPR, Revision 7, *ZPPR Documented Safety Analysis*.

2.4.2.1. Historical Background and Transition Activities

The Board reviewed ZPPR Facility safety basis documents, including:

- ANL-7471, *Final Safety Analysis Report [FSAR] on the Zero Power Plutonium Reactor (ZPPR) Facility*, dated June 1972

- The currently approved BIO for the ZPPR Facility, DSA-006-ZPPR, *ZPPR Documented Safety Analysis*, Revision 7, approved March 29, 2010
- Sections of the DRAFT SAR-412, *Basis for Interim Operation for the Zero Power Physics Reactor Complex (MFC-775/776/784)*, Revision 0, as submitted to DOE for review and approval on September 27, 2011

The entire chronology of the ZPPR safety basis is provided in Appendix F.

Until 1992, ZPPR operated as a research reactor facility under ANL-7471, which provided the safety basis governing its operation. In 1992, the ZPPR Reactor was placed in non-operational standby, but the ZPPR Facility continued to operate under ANL-7471 for various research purposes. In 2005, the ZPPR safety basis was changed in an effort to reflect the facility's modified mission, which included transuranic fuel storage, packaging, and shipping operations. Over the past two decades, such packaging and shipping operations at the ZPPR Facility have been routine for the stored fuel.

The new safety basis, DSA-006-ZPPR, *ZPPR Documented Safety Analysis*, Revision 0, was developed using guidance from DOE-STD-3011-2002, *Guidance for Preparation of Basis for Interim Operation (BIO) Documents*. This BIO was reviewed by the DOE Argonne Site Office using guidance from DOE-STD-l104-96, *Review and Approval of Nuclear Facility Safety Basis Documents (Documented Safety Analyses and Technical Safety Requirements)*, Change Notice No.1, May 2002, and approved on January 27, 2005.

In the safety evaluation report (SER) approving DSA-006-ZPPR, Revision 0, the Argonne Site Office specified several conditions of approval (COAs) that were to be completed and included in the first annual update, including:

- Perform unmitigated calculations without taking credit for leak path factors so that it is apparent that structures along the leak path are not required to meet accident guidelines in the next annual update. (COA 3.3a)
- A discussion of environmental protection shall be added per DOE-STD-3009 in the next annual update. (COA 3.3b)
- A discussion of the qualitative evaluation of worker accident consequences for the facility worker as well as a discussion of major features protecting the workers from the hazards of facility operation shall be added per DOE-STD-3009 in the next annual update. (COA 3.3c)
- In the next annual update, ANL-W should identify assumptions requiring technical safety requirement (TSR) coverage in Chapter 4 of the DSA per DOE-STD-3009. These assumptions would be the limiting inventories of radionuclides and hazardous materials used in the accident analysis (material at risk). (COA 4.3)

Upon reviewing BEA's 2006 annual update to DSA-006-ZPPR, DOE-ID determined these COAs to be satisfied and subsequently, in the SER, dated June 20, 2006, approved Revision 2 of the BIO.

The ZPPR Facility safety basis BIO is updated annually, and at the time of this accident, the ZPPR Facility was operating under Revision 7 of DSA-006-ZPPR while the recently submitted Revision 8 was still under review.

However, in an ongoing effort to upgrade all MFC facility safety bases, as directed by DOE-ID, BEA committed to plan NS-18308, *MFC Work Plan for Safety Basis Upgrade*; this plan is currently in Revision 5. NS-18308 was developed after both DOE-ID and BEA recognized deficiencies in the current safety bases of the MFC facilities. Most notably, there was an absence of properly calculated collocated worker design basis accident dose consequences. Under NS-18308, Revision 5, the upgrade of the ZPPR Facility safety basis was to be submitted for review and approval by December 2011.

On September 27, 2011, BEA submitted SAR-412, *Basis for Interim Operation for the Zero Power Physics Reactor Complex (MFC-775/776/784)*, Revision 0, and TSR-412, *Technical Safety Requirements for the Zero Power Physics Reactor Complex (MFC-775/776/784)*, Revision 0, to DOE-ID for review and approval. The submittal of SAR-412 and TSR-412 was commensurate with BEA's NS-18308 commitment, and upon approval and implementation of this new ZPPR BIO, BEA requested that they supersede the current safety basis, DSA-006-ZPPR.

However, in an effort to quickly gain approval to extend the scope of operations at the ZPPR Facility, a relatively minor annual safety basis revision/update (Revision 8) had been submitted to DOE-ID prior to the upgraded safety basis and was under review. BEA expected that the update could be reviewed and approved more expeditiously than the more extensive upgrade, thereby allowing the additional planned work to move forward.

Analysis

The Board reviewed SAR-412 and found notable differences between the current safety basis and what is intended to supersede it. For example, where previously no safety-class or safety-significant SSCs were identified for the ZPPR Facility, there are now three: the Criticality Alarm System, the Building Walls and Berm, and (potentially most relevant to this accident investigation) the Pu Plate and Pin Jackets. Consistent with this change, the risk associated with a breached Pu fuel plate hazard was assessed in SAR-412, Chapter 3 (Table 3-11, #24), to fall within Risk Bin 7, which assumes the accident is of "Anticipated" likelihood, but still of "Negligible" consequence. Though this change from the current BIO still appears to be analytically unsupported, it does acknowledge the failed Pu fuel plate hazard, which was previously unrecognized.

A combination of DOE-ID oversight and BEA self-assessment and assurance led to the development of a safety basis upgrade plan, as captured by NS-18308. Both organizations recognized deficiencies in MFC facility safety bases and identified the need to improve them. However, the effort that has been taken to implement NS-18308 and ensure that the MFC facility safety bases get the corrections and enhancements that are needed has failed to result in a ZPPR safety basis that correctly characterizes the hazards associated with the operation of the facility.

> The Board concluded that the DOE-ID and BEA oversight systems were not managed in such a way that they could readily identify and correct legacy deficiencies in the technical bases supporting the ZPPR safety basis. **[JON 1, JON 3]**

2.4.2.2. Hazard and Accident Analysis

As discussed, the Board reviewed the current revision of DSA-006-ZPPR (Revision 7). This review revealed that BEA identified and assigned a level of risk to multiple potential accidents and hazardous events. The results of BEA's hazard evaluation and accident analysis are provided in Tables 3-8 and 3-9 of DSA-006-ZPPR. The Board's review of these results showed that all hazards involving Pu fuel plates were identified as having "Negligible" severity and "Extremely Unlikely" or "Beyond Extremely Unlikely" likelihood. Of the bounding accidents and their variations that BEA analyzed for dose consequence, none of them challenged the selected worker or public dose guidelines, as shown in Table 3-9 of DSA-006-ZPPR. As a result, BEA identified no safety-class or safety-significant SSCs for the ZPPR Facility.

During this investigation, BEA explained how dose consequences were analyzed for the identified hazards. This discussion indicated that for ZPPR Workroom accidents, such as the "Failure of workroom hood" and "Dropped Pu fuel plate leading to ignition of fuel plate" (DSA-006-ZPPR, Table 3-8), worker dose was calculated at a distance of 200 meters (m), taking credit for a stack release and resulting atmospheric dispersion. As stated in DSA-006-ZPPR, Rev. 7, Section 3.7.3, the following equation is used to calculate both the mitigated and unmitigated dose:

$$CED_{(i)} = \left(\frac{\chi}{Q}\right) \cdot BR \cdot F_{TR} \cdot Q_{(i)} \cdot F_{(i)} \cdot H_{50(i)}$$

where:

$CED_{(i)}$ = committed effective dose for nuclide (i), mSv
(χ/Q) = atmospheric (air) dispersion value (s/m^3)
BR = breathing rate, 3.47E-04 (m^3/s)
F_{TR} = dose reduction factor due to plume travel and receptor exposure time, conservatively set to 1.00
$Q_{(i)}$ = unmitigated nuclide (i) source term, bq
$F_{(i)}$ = composite source term mitigation factor for nuclide (i)
$H_{50(i)}$ = effective dose coefficient due to inhalation for nuclide (i), mSv/bq, based on International Commission on Radiation Protection (ICRP)-68 values

The atmospheric dispersion coefficient (χ/Q) used by BEA, in both the mitigated and unmitigated dose analysis, to characterize the release to a receptor 200 m away from the source was 2.8E-03 s/m^3.

Analysis

Though the safety basis BIO does not distinguish between collocated workers and facility workers, it is clear that dose consequences calculated for a receptor 200 m from the source would not be representative of a facility worker. Therefore, there is no indication that BEA's analyses considered dose consequence to workers at the location of the release. A calculation of dose consequence to a worker located in the immediate vicinity of the released source term material (i.e., a facility worker) would have to have negate any credit for atmospheric, or air, dispersion. Total inhalation of the available material would typically be assumed to be directly proportional to the breathing rate. Simply stated, BEA's use of the above equation would be appropriate for the calculation of the facility worker dose *if* the $^{\chi}/_{Q}$ value were set to unity. Consequently, the dose to the facility worker would be expected to be at least three orders of magnitude higher than that calculated for a worker 200 m away (based upon BEA's atmospheric dispersion coefficient, 2.8E-03 s/m^3).

In addition, as a general conservative principle of design basis accident dose consequence analysis, the dose associated with manual actions and transit between locations during an event, often referred to as "mission dose," is assessed and added to the total accumulated dose. Such assessments would require an analysis of various human factors and typically rely on evacuation drill data or similar information to support assumptions.

Based on the information provided by BEA, there is no indication that such mission doses were assessed in their analyses. Therefore, potentially non-conservative accident analyses are used to support BEA's safety basis conclusions.

It is of note that the annual exposure limit for ^{239}Pu uptake is measured in nanocurie (billionth of a Ci) amounts, and the single Pu fuel plate involved in the accident was measured in the tens of Ci. Therefore, even if the BR, $F_{(i)}$, and $H_{50(i)}$ factors totaled a reduction factor of one million, the Q value necessary to produce an unacceptable $CED_{(i)}$ would be about one millionth of the ^{239}Pu material contained in the single Pu fuel plate.

2.4.2.3. Safety SSCs and Passive Design Features – Pu Fuel Plate

Upon inspection of Table 3-8 in DSA-006-ZPPR, the Board found that the accident initiator titled "Corroded/ failed fuel plate" was determined to be "Extremely Unlikely," of "Negligible" severity, and of "Acceptable" risk for Pu fuel plates. Associated with this Chapter 3 determination, DSA-006-ZPPR, Chapter 4, *Safety SSCs and Passive Design Features*, identifies the Pu fuel plate jacket as a passive design feature important to safety.

By researching ORPS and other historical evidence regarding Pu fuel plate failures, the Board discovered that various failures of degraded and/or defective Pu fuel plates have been reported. Dating back to 1972, more than five Pu fuel plates have been determined to be leaking, degraded, or contaminated (see Table 2-3, *Pu Fuel Plate Failure History*). BEA has given no indication to the Board that knowledge of these Pu fuel plate failures was well-understood or accounted for in the design and operation of the ZPPR Facility prior to the November 8, 2011, accident.

Table 2-3. Pu Fuel Plate Failure History

Date	Description
11/08/2011	Pu fuel plate in this accident. Clamshell 45 M labeled "OPEN IN HOOD" (refer to 7/15/82)
03/26/1991	PuAl plate – ORPS report NE-CH-AA-ANLW-1991-0002
March 1986	Dented and contaminated plates added to clamshell 47 S
07/15/1982	Swollen fuel plate placed in clamshell 45 M – Labeled "OPEN IN HOOD"
03/28/1974	Failed ZPR Fuel Plate #3-F-372
03/05/1974	Failed ZPPR Fuel Plate Element #5-515-51 - Memo from Material Science Division described "oil-canning" U-28Pu-2.5 Mo fuel element
06/16/1972	Defected ZPPR Fuel plate 658-4006

The Board also identified that the BEA report titled *Transmittal of the INL Transition Report on Nuclear Facilities Safety Bases*, dated January 14, 2005, contained information regarding degradation problems involving stored Pu material at ZPPR.

BEA personnel involved in the safety basis update, upgrade, and revision processes indicated that one of the primary drivers for changing the likelihood of the failed Pu fuel plate hazard, as expressed in the safety basis, was information received from the MFC Independent Safety Review Committee (ISRC) Chairman. According to INL Document ID CTR-207, *Independent Safety Review Committee (ISRC) for the Materials and Fuels Complex (MFC)*, the MFC ISRC is chartered to "provide independent oversight and review of safety basis documents associated with 10 CFR 830, Subpart B nuclear facilities and operational activities and Less Than Hazard Category 3 facilities and operational activities to ensure attention to safety requirements." On January 26, 2009, the sitting MFC ISRC Chairman shared a white paper with MFC management, including the MFC Nuclear Safety Engineering Technical Lead, expressing a concern about the condition of the stored ZPPR Pu fuel plates. The MFC ISRC Chairman characterized the potential for finding failed Pu fuel plates in the ZPPR Vault as "greater than facility and senior management realize[s]." In the white paper, the ISRC Chairman recommends addressing the Pu fuel plate issues with the Laboratory and Hot Cell Services Division Director and the Fuel Manufacturing Department Manager. The Chairman goes on to further recommend having "proper procedures in place, if a failed ZPPR ^{239}Pu plate is discovered." On June 23, 2011, the MFC ISRC Chairman conveyed his concerns to the newly appointed MFC Director of Nuclear Operations. The Chairman's concerns did not result in filing a potential inadequacy of the safety analysis (PISA) or other formal corrective actions. DOE-ID indicated to the Board that they were not aware of the MFC ISRC Chairman's white paper.

Analysis

BEA gave an unclear, and unexplained, basis for determining that both the existence of a failed Pu fuel plate and the failure of a Pu fuel plate jacket would be "Extremely Unlikely" (i.e., equivalent to less than $2x10^{-5}$ per year). Potential clues to the origin of this determination are found in Sections 3.7.5 and 4.3 of DSA-006-ZPPR. In these sections, BEA identified only one Pu fuel plate defect that resulted in the formation of oxides and hydrides (i.e., corrosion), after BEA had performed numerous visual examinations. However, as shown above in Table 2-3, the Board reviewed information from several resources, including ORPS, and identified numerous documented Pu fuel plate failures dating back to the early stages of ZPPR Reactor operation.

BEA provided no quantitative analysis to justify the "Extremely Unlikely" determination, and the Pu fuel plate failure history discovered by the Board (and shown in Table 2-3) alone would call into question BEA's unverified failure rate assumption of "less than $2x10^{-5}$ per year." The ZPPR safety basis credits an inspection for verifying that existing Pu fuel plate failures are discovered, and the safety basis relies upon this inspection, as specified in DSA-006-ZPPR, AC 5.16, *Fuel Storage Component Inspection Program*.

With regard to the white paper from the MFC ISRC Chairman, the concerns about the conditions of Pu fuel plates were clearly communicated to MFC Nuclear Operations management. However, neither of the Chairman's attempts to communicate these concerns was entered into a formal communication, comment, or memorandum process.

The facts indicate that the potential for the November 8, 2011, accident and its associated hazard at MFC was known, but that knowledge was not effectively transferred to those best equipped to act on it.

In addition, BEA developed SAR-412 in accordance with the plan (NS-18308) to address MFC-wide safety basis deficiencies. Revision 2 of NS-18308 notes that, upon declaring a PISA and entering the associated process on August 21, 2006, interim controls were established to maintain the MFC Hazard Category 2 and 3 nuclear facilities/activities in a safe condition. One such interim control reads:

> *If a condition/situation is identified during the MFC DSA upgrade process that warrants entering the PISA/USQ* [unreviewed safety question] *process so that compensatory controls can be developed and put in place for worker/public protection, then immediate action appropriate to the circumstances will be taken.*

The treatment of a failed Pu fuel plate hazard and potential accident in BEA's safety basis is of supreme relevance to this accident investigation, because it ultimately resulted in the lack of additional controls that could have prevented the accident on November 8, 2011. In addition, making this determination in the primary authorization document for the facility helped shape the ZPPR culture for Pu handling operations.

The Board concluded that BEA failed to recognize the significance of and take appropriate action in response to available information regarding the material condition of Pu fuel plates. **[JON 1, JON 2]**

The Board concluded that actual Pu fuel plate failures were not reviewed in the appropriate context to lead to changing the observed failure rate as stated in the safety basis. As a result, workers were at increased risk of exposure to uncontrolled radioactive material. **[JON 2]**

2.4.2.4. Defense-in-Depth SSCs – Hoods

The Board reviewed the available design information and performance criteria for the Workroom South Hood, where the packaging activity was conducted. While the Reactor was operating, the Workroom hoods were used for staging and inspection of fuel, and drawers to be loaded into the ZPPR Reactor. Page 98 of the original ZPPR Facility final safety analysis report (FSAR) states that "The handling of fuel in suspect inspection hoods and in the loading hood precludes any appreciable inhalation hazard to personnel." In 2005, the ZPPR FSAR was replaced with the BIO, DSA-006-ZPPR, which in the current revision (Rev. 7), Section 4.6, identifies defense-in-depth (DID) SSCs. Among those identified, BEA cites "Hoods and glove boxes" in Table 4-2 as DID systems.

In May 2004, the ventilation system was modified by adding adjustable dampers downstream of the hoods. A USQ screen of the proposed system modification was completed on March 26, 2004. In the USQ screen, the basis for this modification included in part the following statement: "…which calls for not exceeding 125 fpm so as not to stir up contamination and leak it from the hood to the room environment." The post-work testing was performed in June 2004 (Work Request No. 534463) and documented the face velocity of the Workroom South Hood at 121 fpm with fan EFS-107A energized and 107 fpm with fan EFS-107B energized.

As currently configured, the ventilation flow through the Workroom is established by supply air delivered to the Vault and exhausted from the Workroom primarily though the North Hood, South Hood, and Shipping Container Hood by exhaust fans located in the Equipment Room. Two louvers are located in the wall adjoining the Vault and Workroom, which is the normal ventilation pathway when the Vault door is closed. Air flow in the ZPPR Workroom is discussed in more detail in Section 2.4.3.2.

The Workroom hoods are essentially benches with a hood over the work area. The face openings of the hoods are approximately 163 inches wide by 11 inches high. Two sliding shields, approximately 12 inches wide, are on the face of the South Hood and can be moved and used to provide additional radiological protection when required. All three hoods in the

Workroom have adjustable dampers in the downstream ducting to allow adjustment of their respective face velocities.

Air flow checks of the Workroom hoods are performed quarterly. The Board discovered that on several occasions, MFC management accepted air flow values in excess of the new design value of 125 fpm without comment or correction. Additionally, the quarterly checks are performed in accordance with TPR-14602, *Testing Specialized Ventilation System*, which directs air flows to be adjusted to 80-150 fpm. Again, a range was deemed acceptable even though it exceeded the 125 fpm limit established by the modification.

Analysis

DOE-STD-1128-2008, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*, acknowledges the challenges associated with handling plutonium outside of containment, and indicates that it is appropriate to make very limited use of hoods for handling plutonium. However, the ZPPR Facility safety basis provides no confinement factor associated with the Workroom hoods. Also, based on the history of Workroom hood testing, BEA has disregarded its own limits for face velocity by accepting test results above those deemed acceptable. Due to the mechanical limitations of hoods, as well as inconsistent testing and maintenance practices, taking credit in the safety basis for the Workroom South Hood's mitigation of airborne releases of particulate transuranic material is questionable at best. Therefore, because the proper configuration could not be assured and the quantitative effect was not estimated, crediting this SSC for DID was inappropriate.

The Board concluded that the ZPPR Facility safety basis does not quantify the credit associated with the ZPPR Workroom South Hood for mitigating accidental releases of radioactive material, nor does it provide technical bases for qualifying the Workroom South Hood as a defense-in-depth SSC. **[JON 4]**

The Board concluded that, though credited in the ZPPR safety basis as a defense-in-depth, the ZPPR Workroom South Hood was not maintained in such a way to provide assurance of its performance or operability. **[JON 5]**

2.4.2.5. Defense-in-Depth SSCs – Radiation Monitoring System

In Chapter 4 of DSA-006-ZPPR, the ZPPR Facility safety basis credits the radiation monitoring system as a DID fissionable material hazard mitigation system for the facility and workers. In Chapter 2 of the safety basis, the ZPPR Workroom radiation monitoring system is described as including one alpha air monitor, which samples air exiting the vault; one gamma monitor; one gamma-criticality monitor located on top of each loading hood; and two gamma-criticality monitors located in the Vault. Also, alpha and beta-gamma air monitors upstream and downstream of the ZPPR facility mound-area exhaust filters are described.

BEA performed an evaluation in December 2009 to justify removal of the alpha and beta-gamma monitors. The evaluation is documented in TEV-729, *Evaluate the Need for the ZPPR Exhaust Alpha and Beta/gamma Monitors*. TEV-729 referenced engineering calculations and analysis report (ECAR)-105, *Determination of Potential Airborne Intake at MFC Facilities,* and ECAR-127, *Determine Proper Placement of Routine Air Samplers and CAMs, and Establish CAM Alarm Settings,* to determine the radiation protection "need" for retaining the monitors. The upstream alpha and beta-gamma monitoring system was designed so that the sample was drawn from the four ducts upstream of the high-efficiency particulate air (HEPA) filters. The downstream sample (still operating but planned to be removed upon revision of the safety basis) is drawn from the common duct downstream of the HEPA filters. The TEV-729 evaluation states that:

> *Maintenance of the subject alpha and beta/gamma detectors is costly and recent problems are indicating the need for repair or replacement. Continuous measurement of particulate radioactivity may not be required by facility, environmental, nuclear safety, or radiation protection organizations.*

TEV-729 further justifies no longer needing the system for National Emission Standards for Hazardous Air Pollutants (NESHAPs) reporting based on safety basis assumptions that "sealed" radioactive materials result in negligible design basis dose consequences at the ZPPR Facility.

USQ-2011-259 was performed in April 2011 and approved in March 2011. Question 4 of the USQ form poses the question, "Could the Proposed Change increase the consequences of a malfunction of equipment important to safety previously evaluated in the safety basis?" The answer selected was, "No," based on the following reasoning:

> *Monitoring of the ZPPR suspect exhaust system does not provide immediate warning to the workers during a release of radioactive material in the ZPPR vault/workroom. This area of the ZPPR is monitored by an alpha CAM, which provides sufficient warning of elevated levels of airborne radioactive materials.*

Through conversations with personnel, the Board learned that the alarm for the upstream monitors was located in the fan room, hence the determination that it would not provide immediate warning to workers. This alarm would also be received at the ZPPR Control Room alarm panel, except that the Control Room has not been manned during all operations since the decommissioning and removal of the reactor.

Analysis

The need to remove the alpha and beta-gamma upstream monitors was based on cost issues relevant to maintenance and replacement of the equipment, but no cost/benefit analysis was performed to support the decision. Part of the justification used during the USQ process for removal of the upstream monitors was the assumption that the air monitoring required by the Radiological Control organization was adequate for the Workroom. The USQ discussion states that the alpha CAM monitoring the ZPPR Vault and Workroom provides sufficient warning of elevated levels of airborne radioactive materials; however, because this alpha CAM was located essentially upstream of the Workroom hoods, this statement was not valid for the Workroom, even though ECAR-127 indicated that it was. Additional information regarding the Vault CAM location and its ability to monitor the Workroom is provided in Section 2.4.3.2 of this report.

If the upstream alpha monitoring capabilities had been maintained for DID protection of the facility and workers in accordance with its safety basis description, and if the Control Room alarm panel was required to be monitored during fuel handling activities, then the release of airborne radioactive material associated with this accident would have been more readily detected, especially after visible quantities of unconfined Pu were exposed to the hood air. Instead, personnel were exposed to airborne Pu for more than four minutes before the CAM monitoring the Vault exhaust alarmed and they evacuated the Workroom. During this time, a smear sample was taken and counted and discussions were held between the HPTs and the SS. These actions eventually led to work being stopped, but did not trigger the evacuation that an earlier CAM alarm would have.

2.4.3. Work Planning and Control

Approval was received for a shipment of Pu fuel plates from the ZPPR Facility to a national laboratory in June 2011. Scheduling for this activity at MFC was tracked by an intermediate range schedule and the Plan of the Week (POW) in accordance with LWP-6202, *Facility Scheduling and Resource Forecasting*.

2.4.3.1. Work Management Process

Work planning per Laboratory Work Procedure (LWP)-21220, *Work Management*, governs the work management process at MFC to ensure that work, including planning, performing, and providing feedback, is performed safely. LWP-21220 states:

> *When you enter this process, you will have either new work with a new scope; work that requires revising, periodic reviewing, or field-changing an existing procedure; or work that may already have been evaluated by this process.*

LWP-21220 requires the involvement of several members of management, support staff, performers, and reviewers. Line management is responsible for following the work management process, ensuring proper review of laboratory instructions, ensuring that laboratory instructions are adequate for performing the work safely, authorizing work to proceed, monitoring work periodically to ensure that it is being performed in accordance with controls, ensuring that no change to scope or risk/hazard has occurred, verifying that the work is being accomplished, and conducting pre- and post-activity briefings. A note at the end of the line management responsibility section states that one-over-one line management approval is required when the line manager making the decision has been part of the detailed planning of work. Additionally, support staff and others assigned by line management have responsibilities in execution of the LWP-21220 process.

In the case of the Pu fuel plate packaging activity, a Process Work Sheet (ZPPR-PWS-34) was developed in lieu of following the LWP-21220 process. SP-20.2.1 governs development of Process Work Sheets (PWSs) and states they are to be used for identifying correct procedure reference, process parameters, and order required for an operation. They are performed in a step-by-step manner, unless specified otherwise. The breakout of material in the Workroom hood and subsequent processing into foodpack containers was to be performed in accordance with ZPPR-PWS-34. Section 1, *Purpose*, contains the purpose of the work, which is to provide process parameters for the breakout and packaging of Pu fuel plates, and states that the PWS would be used in conjunction with ZPPR-OI-005, *Nuclear Material Handling*; ZPPR-OI-010, *ZPPR Fuel Storage Container Handling*; EF-OI-007, *9975 Shipping Container Handling*; and other instructions provided by the project. Section 2, *ES&H* [Environment, Safety, and Health] *Requirements*, states, "Any hazards associated with the procedures worked in conjunction with this document are identified and mitigated in those procedures." Section 3, *Precautions/ Limitations and Prerequisites*, states that referenced procedures will specify such requirements to be followed to conduct the work scope. Section 4, *Routing Table*, directs the use of existing ZPPR operating instructions for transfer of material into the hood, breakout of material, and packaging into the 9975 shipping containers. Section 5, *Activity Parameters*, delineates such information as the material type, quantity, and location; it specifically directs breaking out 33 pieces from the clamshells, loading into two foodpack containers, and then packaging the material in a 9975 shipping container per project coordinator/SS direction. There have not been any documents provided to the Board that were used by the project coordinator/SS to provide direction for packaging a foodpack container. Once the material was packaged into foodpack containers, it was to be processed into final 9975 shipping containers per EF-OI-007. Section 5.6, 5.7, and 5.8 of EF-OI-007 detailed loading and leak-testing a Primary Containment Vessel and Secondary Containment Vessel. Of note, under Step 4, Substep 6 directs loading of the material into two foodpack containers. Step 6, *Accountable Material*, directs information to be recorded on the provided table and necessary data to be documented on the narrative sheet.

The Board reviewed *Operating Instructions for the Zero Power Plutonium Reactor*, a cancelled procedure from the reactor operations timeframe. The procedure contained specific direction for action to be taken upon discovery of contaminated or damaged plutonium fuel plates. The procedure further specified that information was to be recorded in the ZPPR Suspect Fuel Log. Interviews with several key personnel indicated that the ZPPR Suspect Fuel Log was not a widely known or utilized resource for information regarding the condition of Pu fuel plates. The Board was provided no evidence to suggest that this resource was used during planning for the fuel transfer under ZPPR-PWS-34.

Analysis

ZPPR-PWS-34 contains work directions within the activity parameters that are not governed by any of the referenced operating instructions. As a result, some work steps did not have an appropriate hazard analysis or accompanying mitigation for loading the material into foodpack containers. The routing table and activity parameters did not refer to specific steps of the referenced operating instructions to clearly direct the work activity. Steps in the suite of procedures also provided the work group with ambiguous direction such as, "as directed by the Shift Supervisor." This ambiguity led to the tape and plastic being removed from the fuel plate at the time of the accident. This action was not specified in the detailed work instructions and was also outside of the original job scope. Implementation of the LWP-21220 process could have resulted in either development of a new stand-alone laboratory instruction specifically written for this activity, or a change in the laboratory instructions governing the work. Both of these approaches would have required a full hazard analysis with additional reviews by subject matter experts in the appropriate areas.

The Board concluded that the use of a PWS for the packaging activity was not consistent with the BEA procedure development process as defined by LWP-21220. **[JON 6]**

The Board concluded that the planning effort did not include a thorough review of available historical data to assist in the work planning process. **[JON 7]**

2.4.3.2. Identification and Control of Radiological Hazards

The hazard identification and analysis of radiological work is initiated during the work planning process. LWP-15021, *ALARA Program and Implementation*, lists specific criteria that trigger an As Low As Reasonably Achievable (ALARA) review. If the expected radiological conditions meet any of those criteria, the job radiological hazards are further identified and analyzed, and radiological hazard controls are developed during the ALARA review process. The information, documented in the ALARA review, including the identification of needed radiological controls, is communicated to the workers in the radiation work permit (RWP) and during the pre-job brief. If triggers are not met, the hazard controls are developed and communicated by the RWP process alone.

For the Pu fuel plate packaging activity, the potential dose to an individual met or exceeded the ALARA review trigger of 200 mrem. No other triggers were identified, including those for loose or airborne contamination levels. During interviews, the Radiological Engineers responsible for development of the ALARA review stated that, based on the safety basis assumption that Pu fuel plate cladding failure was extremely unlikely, loose contamination was not identified as a hazard for the handling and packaging of the Pu fuel plates. The expected radiological conditions and radiological controls and requirements developed by the ALARA review were incorporated into the RWP for the activity.

Section 1 of the ALARA review indicated that the scope of work included handling Pu in the form of sealed plates. Section 2 included a generic description of all radionuclides and associated direct radiation levels characteristic of the entire contents of the ZPPR Vault rather than a discussion specific to the packaging activity. This section also reiterated the fact that the fuel plates "are welded to prevent the escape of any loose contamination." The expected airborne radioactivity levels were determined to be less than 0.3 derived air concentration (DAC).

Section 2 of the ALARA review discussed the radiological conditions expected during the job. The radiological contamination levels provided in the ALARA review for the packaging activity were based on general area surveys of the Vault and Workroom rather than the Pu fuel plate handling activity. A survey map from March 2011 was referenced, even though more current survey data was available; the Radiological Engineer stated that the reason for using the March survey was likely the fact that an earlier ALARA review for ZPPR fuel handling operations was used as a template to begin the Pu fuel plate packaging ALARA review and that text had not been updated. The Radiological Engineer stated that the radiological data from the March 2011 survey did not differ significantly from more recent surveys.

Section 6 of the ALARA review discussed engineering controls. The ALARA review for packaging Pu fuel plates stated, "The primary containers will be opened in the fume hood to prevent the potential spread of contamination." The Radiological Engineers responsible for developing the ALARA review stated that they required the clamshells to be opened in the "fume hood" in case there was "some level of contamination" and that the "fume hood" would be sufficient to handle the "incidental contamination" levels that they considered to be possible. However, the Board was not provided any information that quantified the potential contamination levels the engineers expected. The Radiological Engineers also indicated that the effectiveness of the hood in containing significant quantities of plutonium contaminants was not evaluated during the ALARA review because of the assumption that the plates were seal-welded and failures were considered "extremely unlikely." The Radiological Engineers stated that when they do perform evaluations of engineered controls effectiveness, they use a confinement factor based on the type of control (glovebox, hood, local exhaust, etc.). However, unless something obvious alerts them to ventilation deficiencies, they assume that the tests performed by Industrial Hygiene to ensure that the hoods are performing as designed are valid.

The Board reviewed records that revealed the following facts associated with the Workroom hoods:

- In early 2004, Industrial Hygiene identified a need to lower the face velocity of the hood from a range of 125-200 feet per minute (fpm) to a face velocity "not to exceed 125 fpm." In June 2004, adjustable dampers were installed downstream of the hoods to achieve lower face velocities. Although the North and South Hood velocities were within specifications, the drum hood velocity was recorded at 134 and 137 fpm. This discrepancy was never questioned or corrected.
- In October 2009, Work Order 135531-01 was completed to change out roughing filters. Post-maintenance testing for this evolution required adjusting the Workroom ventilation

system dampers, as necessary, to obtain a hood velocity of 80 to 150 fpm in both the North and South Hoods. This range contradicted the 125 fpm specified in the design modification document and USQ screen. After the work was completed, the resulting corrected average velocity was 137 fpm for the South Hood. This discrepancy was never questioned or corrected.

- The face velocity of the Workroom hoods was checked on a quarterly basis using maintenance instruction ZPPR-MI-500A, *Airflow Readings on Building 775 Workroom Hoods*. The data sheets from those tests indicated the South Hood was a "Class A Hood." TPR-14602 execution required adjusting the Workroom ventilation system dampers, as necessary, to obtain a hood velocity of 80 to 150 fpm in both the North and South Hoods. This contradiction between TPR-14602 and the modification design goal was never identified or corrected by MFC management.

Section 11 of the ALARA review discussed fixed or permanent radiological monitoring instruments. Relative to air monitoring, the ALARA review listed a fixed alpha CAM (i.e., the Vault CAM) "sampling the air exiting the vault" and a portable alpha CAM "which can be used in lieu of the fixed CAM if [it is]…inoperable," stating that job-specific air monitoring is required for opening primary containers and "should be placed in the breathing zone of workers."

The Board reviewed the ECARs that determine the air monitoring requirements and placement of air monitoring equipment at ZPPR. During April 2010, ECAR-105, which contained original analysis for determining air sampling requirements for all MFC facilities, was cancelled and replaced by ECARs 894 through 897. ECAR-897 includes the information for the ZPPR Facility. Specific air flow studies to support the air sampling requirements are documented in ECAR-127. Review of the most recent air flow study (see Figure 2-5) revealed that the evaluation included neither the descriptions of the room/facility conditions during testing (e.g., ventilation status, doors open/closed, personnel positioned in front of the hood) nor a legend defining the symbols used to indicate flow descriptions. In reference to the ZPPR Vault and Workroom, the most current revision of ECAR-127 states:

> *The general air flow goes out of the vault and is directed onto the alpha CAM mounted on the wall and then to the hood in the work room. A portable CAM is positioned in the immediate work area when needed. The vault and work room are well characterized by CAMs.*

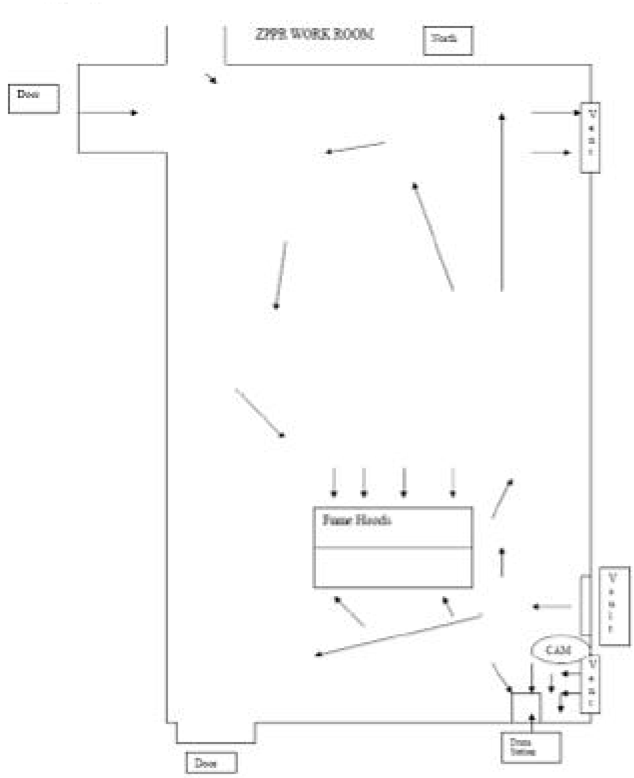


Figure 2-5. ZPPR Workroom Ventilation Air Flow from ECAR-127

The evaluation to determine air sampling requirements for the ZPPR Vault and workroom states:

> *Since the I_f* [intake fraction of the annual limit on intake] *is greater than 1, this indicates a high level hazard which requires a CAM per MCP-352, Appendix B (Table 2 in this document).*
>
> ***Recommendation:*** *Based on the air flow study in ECAR-127, and work activities in the ZPPR workroom and vault, the* [Vault] *CAM should remain in the same location.*

This evaluation was in error. MCP-352, *Determining Radiological Air Monitoring Requirements*, Appendix C, *Design and Placement Criteria*, states that monitors must not be located in front of the room air supply. The air flow study presented in ECAR-127 demonstrates that the air flow in the Workroom is not directed in such a way to allow the Vault CAM to monitor the air representative of work in or near the hood.

Section 13 of the ALARA review discussed anticipated difficulties and relative contingency plans, including applicable abnormal or emergency procedures. The ALARA review for the Pu fuel plate packaging referenced ZPPR operating procedures, abnormal response requirements, and routine emergency response procedures but did not discuss response to difficulties or abnormal conditions that could be encountered specifically during Pu fuel plate packaging activities.

The ALARA review and RWP did not account for appreciable removable contamination levels. Consequently, the personal protective equipment (PPE) required for personnel was minimal (i.e., lab coat and a single set of gloves for handling clamshells outside hood, and only a set of nitrile gloves for the HPT counting smears). Although no removable contamination was expected during the packaging activities, the RWP evaluation points were established at 10,000 dpm/100 cm^2 beta-gamma and 200 dpm/100 cm^2 alpha, which is a factor of 10 higher than expected. Those evaluation points were applicable to contamination levels detected on the clamshell cart. Evaluation points established for inside the hood were 100,000 dpm/100 cm^2 beta-gamma and 2000 dpm/100 cm^2 alpha, which is a factor of 100 higher than expected. There was no limiting condition that voided the RWP (and therefore forced a work stoppage) for contamination levels inside the Hood or in the general Workroom area itself. The only limiting condition that voided the RWP was for loose contamination on the cart.

Analysis

The rigor of the hazards analysis performed specifically for the Pu fuel plate packaging activities was not commensurate with the controls established to mitigate those hazards. Over-reliance on the hood by workers and management contributed to their complacency when faced with the abnormal situation of clamshells containing potentially damaged fuel.

The Vault alpha CAM is located in the Workroom approximately 15 feet from the South Hood, positioned to monitor the Vault exhaust. The inadequate air flow studies and recommendations provided by ECAR-127 led to the Vault exhaust CAM being inappropriately identified as the air monitoring of choice for the Pu fuel plate packaging activities. The ALARA review should have identified the portable CAM placed near the immediate work area instead.

The ALARA review and RWP (which was based on the ALARA review) did not consider significant levels of removable contamination because of the safety basis assumption that a Pu fuel plate cladding failure was extremely unlikely. BEA established evaluation points to ensure that Radiological Control management and/or radiological engineering staff would be consulted to determine whether the controls in place are adequate for the conditions encountered. BEA also established the limiting conditions under which work should be stopped and a new evaluation conducted (revision of the ALARA review and RWP is typically required) However, the evaluation points and limiting conditions reflected the assumption that high levels of removable contamination were unlikely, even though conservative limiting conditions relative to abnormal situations were warranted in the RWP because the ALARA review analysis was based on best-case (rather than worst-case) scenarios. The limiting conditions to void the RWP and stop work should have been developed to reflect unacceptable levels in the general area, on the clamshell cart and clamshells, and inside the hood. Further, because the RWP did not establish any limiting condition relative to contamination levels in the hood, the work could have been allowed to continue regardless of the smear results taken after cutting the bag, without additional hazard evaluation by radiological engineering. Finally, the ALARA review did not address response to unexpected conditions specific to the activity.

> The Board concluded that the evaluation points and limiting conditions developed by the As Low As Reasonably Achievable (ALARA) review and required by the RWP were insufficient to result in stopping work and re-evaluating the hazards when unanalyzed/unexpected hazards transpired. **[JON 8]**

> The Board concluded that although the Vault CAM alarmed in response to the event as designed, its placement, as determined in engineering evaluations, was not optimal for the work being performed in the Workroom hood. **[JON 9]**

2.4.3.3. Approval and Authorization of Work

ZPPR-PWS-34 was approved by the NFM on November 3, 2011, with an effective date of November 10, 2011. The activity appeared on the POW dated November 3, 2011. Through interviews, it was determined that the work was released to be performed on November 8, 2011. The POW provided to the Board did not contain the NFM authorization signature required by LWP-6202 and did not go into effect until November 10, 2011.

The Radiological Control Manager's signature was not on the approval page of the ALARA review. Instead, the approval page was signed by an MFC Radiological Control Supervisor on November 2, 2011. Section 4.6 of LWP-15021 requires that the Radiological Control Manager review and approve ALARA review packages for moderate and high risk work to confirm that the procedural requirements for the initial ALARA review have been met and that the appropriate radiological controls have been specified.

The RWP was approved by the NFM, the SS, and the ZPPR Radiological Control Supervisor on November 2, 2011. The Radiological Control Supervisor who signed the ALARA review approved the RWP on November 3, 2011.

Analysis

The activity was placed on the POW and subsequently released to be performed even though the PWS was not considered effective until November 10, 2011. The Radiological Control Manager did not review the ALARA package to ensure that moderate and high risk work was reviewed and authorized by the appropriate level of management. The absence of these reviews represents an absence of rigor in the authorization and release of work.

2.4.3.4. Execution of Work

A pre-job brief was conducted before work began on the activity in accordance with LWP-9201, *Briefings*. The briefing discussed the procedures to be used and included "what if" casualty scenarios.

The work was conducted in accordance with ZPPR-PWS-34, which referenced and provided sequencing for existing operating instructions ZPPR-OI-005, ZPPR-OI-010, and EF-OI-007. A review of the RWP system reports for RWP sign-on and sign-off revealed that all personnel involved in the work activity on November 8, 2011, were signed onto the RWP, with the exception of the SS. The general area was physically posted as a Radioactive Material Area and Radiological Buffer Area. Neither requires an RWP for entry. However, the expected radiation levels at 30 cm were 8 to 12 mrem/hr; these levels require that the area be posted as a Radiation Area (RA) and that workers sign onto an RWP. According to interviews, the intention was that the HPTs would control access by continuous observation, as allowed in accordance with 10 CFR 835. However, the video showed that the SS was inside the 30 cm boundary during the evolution.

Procedure ZPPR-OI-010, Subsection 5.2 provided work steps for opening a container in the ZPPR Workroom hood. Substep 5.2.5 of this procedure directed performing operations as directed by the SS. Step 5.2.5.1 stated that “if removing the material (breakout) from the container, THEN breakout material per an approved PWS.”

During transfer of the four clamshells from the Vault to the Workroom South Hood, workers observed radioactive material labels on two of the clamshells. The label on the 45M clamshell stated, “Open in hood . . . swollen upper left corner near number.” It was dated 7-15-1982 and initialed. (See Figure 2-6.) The label on the 47 S clamshell stated, “1-Plate dented, 1-plate contaminated, < 10 d/m/plate α & is wrapped in plastic” and was dated April 1, 1986. (See Figure 2-7.) In addition, the writing on the 47 S clamshell itself included a statement to “check monthly.” After observing the labels, workers initiated a work “time out,” prompting a phone call from the SS to the NFM. The result of the discussion was a decision to proceed with the activity.

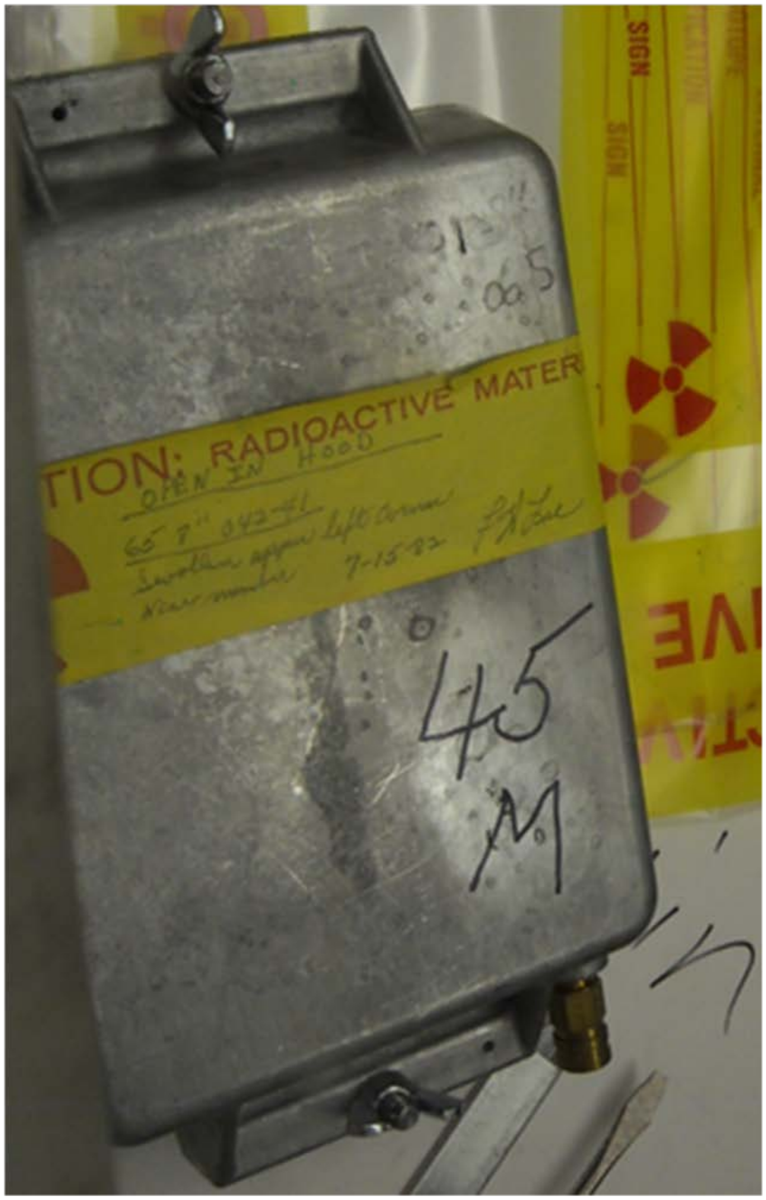


Figure 2-6. Clamshell Number 45 M

Figure 2-7. Clamshell Number 47 S

As work progressed and the unexpected radiological conditions of the clamshell contents surfaced, personnel began to work outside the RWP bounds. For example, the SS became heavily involved within the area that should have been designated as the RA, without signing onto the RWP. Also, HPT-2 was wearing PPE that only allowed him to count smears, but video evidence documented that his hands actually broke the plane of the hood to retrieve smears.

At this point in the evolution, the first clamshell (45 M) was opened, revealing a single fuel plate wrapped in plastic material and bound by tape. The RWP provided no limiting conditions for contamination levels inside the hood; the limiting conditions for loose surface contamination applied exclusively to external surfaces of the clamshell and transfer cart. After verification that there was no removable contamination in the clamshell, OP-1 cut the plastic and tape on the fuel plate, as directed by the SS. When the plate was turned over to cut the other side, powder was observed on the inside of the clamshell. A smear sample was taken near the powder, and the clamshell was closed. The smear "pegged" the frisker on the lowest scale (later counted on December 8, 2001 and found to contain 5.5 million dpm alpha). Approximately three minutes after the plastic was cut, the Vault CAM alarmed which then initiated an evacuation of the Workroom. Figure 2-8 shows the work area in the South Hood with Clamshell 45 M, the foodpack, and the knife used to cut the plastic wrapping.

Figure 2-8. Re-entry Photo of Work Area in South Hood

Analysis

The Board determined that approved procedures were not followed for the operations conducted inside the Workroom South Hood. The SS was given implied authority to direct operations in the South Hood without steps being written in the operating instructions with the "as directed by the SS" step. This allowed the Shift Supervisor to continue work without properly analyzing the information that was on the label attached to the clamshell.

Additionally, the SS involvement without being signed onto the RWP and HPT-2 taking action inside the hood without the prescribed PPE, were important factors that should have alerted the workers to the abnormal situation and the subsequent "scope creep." These conditions should have prompted them to stop work and re-evaluate the situation. However, the work was allowed to continue without proper analysis of new situational hazards and implementation of additional controls.

The Board concluded that the work group failed to realize that the additional steps to cut the wrapping material from the fuel plate were outside the boundaries of the RWP and should have resulted in stopping work. **[JON 10]**

The Board concluded that the work group performed operations to cut the wrapping material from the fuel plate without an approved procedure step to direct the action. **[JON 10]**

The Board concluded the training provided by MFC00027 and other training experiences did not inform the workers adequately to alert them to stop working when they encountered the abnormal condition of multiple wraps of plastic and red tape after opening the clamshell. **[JON 11]**

2.4.3.5. Training Qualification and Proficiency

The Board reviewed the training requirements, qualification records, and proficiencies for the personnel involved in the repackaging of Pu fuel plates. Both general site training and the training specific to the ZPPR Facility were reviewed; the latter was required only for operator and supervisor positions. These two positions, the Fissile Material Handler (FMH) and the Fissile Material Handler Supervisor (FMHS), required certification that was considered to constitute a higher level of accomplishment than qualification. The training program specific to the ZPPR Facility, as defined in Program Description Document (PDD)-147, applies to the following positions:

- Manager: NFM
- Supervisor: SS or Facility Area Supervisor (FAS) who certifies FMHS
- Workers: Nuclear Facility Operators (NFOs) who certifies FMH.

PDD-147 Training and Qualification Requirements

Managers

Managers and technical staff are considered qualified by virtue of meeting the entry-level requirements associated with their positions and by completing applicable position-specific training. Position-specific training may be identified in qualification cards or Individual Training Plans. NFMs must complete a qualification checklist that covers management/ supervisory skills, ES&H operations, and the nuclear safety basis. No comprehensive examination is administered to determine their qualification, but continuing training programs are implemented to meet the needs of the individual and position. Completion of the NFM qualification or Nuclear Support Manager qualification training fulfills the core facility-specific training requirements.

Operators and Supervisors

Qualification/requalification of operators and supervisors includes examinations applicable to their positions. Qualification/requalification is only granted after ensuring that requirements (including training, examinations, and other specified requirements) have been satisfactorily completed.

Facility-Specific Training

Facility-specific training is provided to personnel who routinely require unescorted access to MFC operating facilities/areas to give them the information necessary for their safety while in the facility/area. It includes the following topics: facility description, access controls, facility hazards, facility safety systems, hazardous materials, emergency response requirements and safety equipment, and general administrative and security procedures.

Training Progression

At ZPPR, the NFO and FAS require qualifications. Operations personnel certify as FMHs and FMHSs.

An NFO is required to simultaneously qualify to the MFC Basic Operator Qualification (BOQ) course and certify as a *facility specific FMH*. NFO candidates complete the MFC BOQ course concurrent with facility-specific NFO qualification and/or certification. The MFC BOQ is a trainee qualification verifying achievement of fundamental knowledge of theory, basic system components, and operations related to general facility operation; it does not qualify the NFO candidate to perform any facility-specific work independently. The BOQ qualification is a one-time-only qualification and does not require examinations, continuing training, or requalification. Pu awareness training is completed during BOQ qualification. Qualification cards are used to complete the requirements for qualification and identify the specific knowledge and skills that will be demonstrated for qualification. A trainee performs on-the-job training (OJT) under the direct supervision of an NFO/FAS. NFO operational performance is evaluated by an NFO/FAS.

FMH and FMHS positions are certified positions. Qualification cards are used to complete the requirements for certification and identify the specific knowledge and skills that are demonstrated for certification. An FMH trainee performs OJT under the direct supervision of an FMH/FMHS. FMH operational performance is evaluated by an FMH/FMHS.

Proficiency

To maintain active status, ZPPR certified FMHs and FMHSs demonstrate proficiency by performing (or simulating if necessary) fuel handling, transfer, or storage activities at least once every three months. Proficiency is documented and tracked by the facility management. If proficiency is not maintained, certification is suspended by facility management, and the employee is not assigned duties requiring certification. Proficiency status is reported to the training system database.

Prior to a worker resuming duties associated with certification, the ZPPR Manager will ensure that:

- Certification is otherwise current and valid.
- The FMH or FMHS has performed certification duties under the direct supervision of a certified FMH or FMHS, as appropriate to the position, for a minimum of one fuel handling, transfer, or storage activity.

The Board verified the SS's and Operators' FMH and FMHS proficiencies records were current.

Radiological Engineer Training and Qualifications

Section 4.6.4 of LWP-15021, *ALARA Program and Implementation,* requires that the Radiological Control Manager ensure that personnel assigned to conduct ALARA reviews are trained and familiar with unique facility hazards and effective control requirements. The Radiological Engineer who developed the ALARA review had not completed the Radiological Engineer qualification, but a qualified Radiological Engineer performed a review and co-signed the final document. During interviews, both Radiological Engineers stated that they had minimal familiarity with the ZPPR operations and historical handling of Pu plates.

The MFC Drill Program

The Board examined the MFC operations drill program in conjunction with the training program. A properly implemented training program that is compliant with DOE Order 5480.20A, Chg. 1, *Nuclear Reactor Safety Design Criteria,* dated January 19, 1993, includes operational evaluations that measure training effectiveness. Notably:

> DOE Order 5480.20A, Chg. 1, Chapter 1, 7.d.(3) requires that "*Continuing Training programs for certified operations personnel shall consist of preplanned classroom-type training, on-the-job training, and operational evaluations on a*

> *regular and continuing basis. Continuing Training shall include, at a minimum, the following as related to job performance: Section (b) drills conducted in the facility or on a simulator to enable operations personnel and operating teams to maintain their ability to respond to abnormal or accident situations. Training operations drills conducted in the facility shall not lead to or have the potential for safety concerns.*

An operations drill program provides a method for identifying and analyzing hazards and for developing and implementing controls, as well as ensuring that drill are conducted safely. The drill program is established in accordance with the training programs of various facilities. The intention of the operations drill program is to foster an awareness of abnormal conditions and to reinforce proper conduct of operations principles. It also provides management with a tool for evaluating the overall ability of personnel to perform in abnormal conditions.

The Board reviewed MFC Drill scenarios for 2010 and 2011 and found that only one radiological drill had been performed at MFC during that time period. There was no evidence that any drill was performed that would have prepared the workforce to respond to an event like the accident (e.g., involving multiple contaminated personnel requiring transport to CFA for whole body counting or chelation therapy). Also, medical and radiological staff stated that none of the drills that were performed would have prepared them to recognize and respond to the human aspects (emotional trauma) of such a radiological event or to ensure that employee assistance program staff responded as well.

Analysis

The Board's review of operator qualifications identified that the NFM, SS, and both Operators were fully qualified in accordance with MFC training requirements. However, the training for NFMs does not include a comprehensive examination to determine their qualification, and the BOQ qualification for Operators is a one-time-only qualification and does not require examinations, continuing training, or requalification.

Pu awareness training is required for Operators (in the BOQ) and HPTs. However, no facility-specific training is required for workers who perform Pu fuel plate packaging, and not all workers had Pu awareness training before the activity. The NFM did not attend Pu awareness training; this training is not part of the NFM qualification training, so the NFM has no opportunity to gain an awareness of the significant hazards associated with a small volume of Pu. Within the past two years, no radiological control or other drills addressed the possibility of evacuating the ZPPR Workroom in the event of a radiological accident. As a result, during the November 8, 2011, Pu release, workers did not fully appreciate the conditions and therefore delayed their evacuation.

The Board concluded that training of MFC employees was not effective in providing the workers with the knowledge needed to recognize that a visible quantity of Pu particulate represented a hazard warranting immediate evacuation. **[JON 11]**

2.4.4. Contractor Assurance System

2.4.4.1. DOE Contractor Assurance System Assessments

The Board reviewed DOE contractor assurance system (CAS) assessments reflecting activities at MFC within the last two years that the Board determined were relevant to the accident. These assessments include Facility Representative (FR) field observations of radiological work (Table 2-4), recent ORPS reportable radiological events (Table 2-5), a summary of DOE radiological program oversight activities (Table 2-6), and a recent DOE-ID quarterly work planning and control evaluations of issues management for conduct of operations, work control, and radiological protection deficiencies. In evaluating this area the Board considered the term "field oversight" to encompass the following:

- The day to day observation of contractor work execution activities by Facility Representatives
- Functional area program reviews by Subject Matter Experts
- Analysis and trending of oversight information used to provide periodic feedback regarding contractor performance
- The formal processes of event investigations, reporting and follow-up such as DOE led "For Cause reviews"

The consideration of this information is an important element in DOE-ID assessment of BEA contract award fee under the Performance Evaluation and Measurement Plan (PEMP). It is important to note that the term "field oversight" does not include the review and approval of nuclear safety basis documents.

Table 2-4. FR Field Observations 2010-2011

DOE Identified Radiological Control Related Findings	
DOE FR Finding ISS-OS-7/1/2010-27638	Poor Contamination Control Practice Observed at HFEF (Multiple Rad Con issues)
DOE FR Finding ISS-OS-7/1/2010-28918	HFEF-14 Cask Procedure and Procedure Performance Inadequate
DOE FR Finding ISS-OS-1/3/2011-20722	Less Than Adequate Contractor Oversight During FERMI Drum Packaging
DOE FR Finding ISS-OS-1/5/2011-57377	Failure of Personnel to Follow Warning in TSDF-OI-009 (FERMI Drum packaging)
DOE FR Finding ISS-OS-1/5/2011-59269	Inadequate Radiological Survey Techniques During FERMI Drum Packaging

DOE Identified Radiological Control Related Findings	
DOE FR Finding ISS-OS-1/5/2011-756	Failure to Follow Procedure Prescribed Hazard Control During FERMI Drum Packaging
DOE FR Finding ISS-OS-3/4/2011-10088	Radiological Work Permit not Bounded for Radiation Levels
DOE FR Finding ISS-OS-4/4/2011-55357	Evaluation Points not Clearly Identified in Work Documents (Rad survey/evaluation points)
DOE FR Finding ISS-OS-4/4/2011-81528	Personnel did not Wear the Required PPE During Job Performance (RWP requirement)
DOE FR Finding ISS-OS-4/5/2011-50007	Work Documents did not Address Hazards, (For Gamma Ray Counting Equipment)
DOE FR Finding ISS-OS-4/5/2011-83939	Failure to Recognize Change in Work Activities (Workers in Anti-Cs)
DOE FR Finding ISS-OS-4/5/2011-88679	ALARA Review Requirements not Incorporated into Work Control Documents
DOE FR Finding ISS-OS-4/5/2011-94919	RWP Lacked Void Point for Hood Contamination Levels
DOE FR Finding ISS-OS-4/5/2011-98976	Failure to Survey After Handling Potentially Contaminated Item
DOE FR Finding ISS-OS-5/4/2011-11785	All ALARA Review Requirements not Incorporated into RWP

The following represents a listing of radiological Occurrence Reports that impacted the oversight activities conducted over the past two years by both DOE and BEA.

Table 2-5: Radiological ORPS Events since September 2, 2010

Date Discovered	Report	Title	Comments
September 2, 2010	NE-ID—BEA-FMF-2010-0001	Failure to take Appropriate Actions when Reaching RWP Hold Point	Categorized September 14, 2010 (12 days late)
November 16, 2010	NE-ID—BEA-HFEF-2010-0001	Personnel Contamination Discovered Following Work in Hot Repair Area	No evaluation given
December 20, 2010	NE-ID—BEA-AL-2010-0002	CAM Alarm from Contamination Release While Performing Modifications on Glovebox	Led to a DOE “For Cause” review.

Date Discovered	Report	Title	Comments
January 7, 2011	NE-ID—BEA-HFEF-2011-0001	Radiological Work Issues Identified Following Abnormally High Extremity Exposure Results	Radiation work had become “routine”. Some operating procedures did not contain appropriate radiological controls incorporated.
March 17, 2011	NE-ID—BEA-INLPROGRM-2011-0001	Radiological Work Control Noncompliance Issues	Recurring based on six ORPS and 14 non-ORPS issues since April 2009.
October 5, 2011	NE-ID—BEA-HFEF-2011-0004	Management Concern Due to Elevated Dose Identified On Extremity Dosimetry	Categorized October 10, 2011, ALARA beta limit was not incorporated into RWP, Work continued after meter read off scale.
November 1, 2011	NE-ID—BEA-FCF-2011-0005	Shoe Contamination Following Suited Entry into High Contamination Area	300,000 dpm beta/gamma and 30,000 dpm alpha, source not identified.
November 8, 2011	NE-ID—BEA-ZPPR-2011-0001	ZPPR Workroom Pu Contamination Event in MFC-775	“The event”

Table 2-6. DOE Radiological Program Oversight Activities since January 2011

Date	Organization	Title	Comments
January 11-13, 2011	DOE-ID	For Cause Review resulting from December 20th Casting Lab Glovebox Event	Resulting in withholding portion of fee
July 25-28, 2011	DOE Office of Health, Safety and Security (HSS)	Independent Review of the Occupational Radiation Protection Program as Implemented and Recently Enhanced at the Idaho National Laboratory.	Areas for improvement: • Interpreting radiation monitoring system data • Verifying training and qualification status of workers • Improving RWP system to make RWPs more job specific
August 29 – September 2, 2011	DOE-ID	Effectiveness Review of Corrective Actions from For Cause Review.	Partially effective No return of fee

DOE-ID Quarterly Evaluations at MFC

The following information was identified in DOE-ID quarterly evaluations at MFC, under DOE Order 226.1B, *Implementation of Department of Energy Oversight Policy*, dated April 25, 2011:

- MFC continues to try to implement the issues management process effectively. Process ownership currently appears tied to the performance levels of the individual managers, with high-performing managers effectively implementing the system and other managers needing improvement. During January 2011, MFC attempted to reduce the number of issues in the corrective action plan (CAP) development phase. Management worked additional hours before and after the normal work day to move these issues through the process. By doing so, approximately 400 issues were moved through to resolution or Corrective Actions Plan (CAP) Implementation where they appear to have languished. MFC continues to lead the INL in overdue issues and actions, accounting for over 82% (over 190) of the past due actions and 80% (over 440) of the past-due issues within the Nuclear Operations Directorate. MFC finished the first quarter of 2011 with approximately 650 issues in the backlog.
- The issues management database is continuing to be populated with new issues. However, there are inconsistencies with the level of information being entered, and the FRs have identified several instances over the previous quarter, where not all of the issues and observations from self-assessments have been entered.
- Formal trending and analysis of issues and operations data for commonalities have not been performed. The top ten discipline percentages reported have undergone a rough evaluation of higher frequency issues that has not identified any vulnerability to date. However, this evaluation is performed only for issues identified by Nuclear Operations. There have been some recent examples of issues trending in conjunction with causal analyses for such events as the radiological work shutdown.

DOE-ID concludes that BEA continues to make improvements in its implementation of all aspects of the operational CAS. Several remaining issues have been discussed with BEA management. DOE-ID remains concerned about the effectiveness of corrective actions and will continue to monitor efforts under way to address longstanding deficiencies in conduct of operations, work control, and radiological protection.

Analysis

The information reviewed by the Board indicates that FRs and other subject matter experts conduct strong field oversight of contractor performance at MFC in work planning and control, the radiological control program, and the CAS. In particular, a For Cause Review was conducted following a series of work control and radiological controls events in January 2011. DOE-ID identified three high-level issues in these key programs. A follow-up assessment in September 2011 concluded that BEA's corrective actions were only partially effective. A percentage of BEA's award fee was withheld, indicating that DOE-ID was committed to improving contractor performance in these areas. Additionally, a team from HSS conducted an independent review of the occupational radiation protection program in July 2011, which acknowledged BEA's improvement efforts while highlighting the need for further action.

The Board concluded that DOE-ID's field oversight at MFC has been appropriately balanced and effective in identifying weaknesses in contractor performance and communicating them to management.

2.4.4.2. BEA Contractor Assurance System Activities

The Board evaluated BEA management observations conducted at MFC in July, August, September, and October 2011. The following are highlights of the evaluation:

- The elevated exposure event in HFEF has led to the discovery through interviews with MFC first line supervisors that there is no clear direction, training, or mentoring, for them regarding where and how to utilize their in-field time.
- Operators have been told to follow procedures so much that they are more worried about the procedure than what is happening with the facility.
- In September 2011, 283 observations were conducted by MFC management resulting in seven ICAMS entries.
- In August, 371 observations were conducted by MFC management. 31 ICAMS entries resulted.
- In July, 273 observations were conducted by MFC management. 16 ICAMS entries resulted.
- Average observations per Line Manager for July, August and September were five, seven, and five respectively.
- MFC provided a leading indicator about health of the organization, "As evidenced by recent events and reviews of the data obtained from the observations, the observers are not being as critical as they need to be when performing observations."
- Trends that are being seen include; planning being effective, job site reviews, stakeholder/customers involvement, and work task/job coordinated.
- The observation program has indicated that work management and work task/job coordination need attention.

Metrics provided to the Board for July, August, and September 2011 identified that written instructions, work management, safety and industrial hygiene, and human performance need improvement.

Analysis

The Board acknowledges that BEA has significantly increased its management presence in the field. In general, the issues identified during these self-assessments are similar to those identified by DOE-ID and HSS. However, the Board's review of these issues indicates that there is a wide range in the quality of BEA's management observation activities. BEA needs to better communicate the MFC Nuclear Operations Director's expectations regarding how these activities are to be conducted. In the absence of clear direction, the content and quality of these activities depend on the competence and experience of the individual performer.

The Board concluded that although there has been a noticeable increase in the number of self-assessments conducted at MFC, they lack the quality and depth needed to consistently identify and correct issues that significantly improve performance. **[JON 13, JON 14]**

2.4.5. Emergency Management and Response

Emergency Plan Implementing procedure (EPI)-92, *MFC Operational Emergency Categorization/Classification and Protective Actions*, provides guidance and defines responsibilities for determining Operational Emergency (OE) categorization/classification based on predetermined emergency action levels (EALs) for events originating at or affecting controlled facilities/areas at MFC. The EPI states, "OE categorization/classification aids in the rapid communication of critical information and initiation of appropriate time-urgent response actions."

Section 4 of EPI-92 provides the emergency action manager (EAM) with instructions for determining initial OE categorization, classification, and protective actions. Additionally, Appendix A of that procedure requires a review of the MFC EALs and compares available data with the appropriate EALs. If the event is described in the MFC EALs or the discretionary EALs, the event is categorized as an OE. Otherwise, facility management is to be notified and requested to categorize the event per LWP-9301, *Event Investigation and Occurrence Reporting.*

The following conditions listed in EPI-91, *MFC Emergency Response Organization Activation*, Section 2, could have resulted in activation of the MFC emergency response organization (ERO):

- An event occurs at an MFC Battelle Energy Alliance, LLC (BEA), controlled building (see Appendix A) and the MFC emergency action manager (EAM) determines the MFC ERO should activate
- An operational emergency (OE) is declared at MFC and it is determined the MFC ERO should activate
- The INL emergency director or Department of Energy Idaho Operations Office management duty officer requests the MFC ERO to activate

In accordance with EPI-92, the EAM is responsible for determining emergency control center (ECC) staffing levels; determining the ECC route and alternate reporting location, if necessary; determining the ERO activation method; activating the ERO; verifying that ECC staffing requirements are met; verifying the operational status of ECC equipment; and briefing the ECC staff.

In the event of a *full* activation, the ERO would be activated in accordance with EPI-91. During the accident, the MFC EAM determined there was no EAL that covered the accident situation; the MFC EAM evoked a discretionary EAL three hours after the contamination.

EPI-91 recognizes that a *partial* activation of the ERO may occur, but EPI-92 does not provide specific instructions for this action.

On November 8, 2011, at 1215, the EAM, Information Manager, Security Leader, Support Manager, and a former FAS who was assigned as the Building Emergency Director first logged into the ERO performance attendance roster in the MFC ECC. According to the EAM's discussion with a Board member, this decision was based on personal observation of personnel in PPE being transported from ZPPR to Experimental Breeder Reactor (EBR)-II.

Table 2-7: Selected Entries from the EOC and MFC ECC Records November 8, 2011

Time (MST)	Log Entry
1215	On duty MFC EAM reported to MFC ECC
1256	Some contaminated individuals transported to EBR-II for decontamination shower
1305	MFC ECC operational
1306	INL Fire Department notified
1328	Warning Communications Center recorded a partial activation
1330	ED reported to EOC
1349	Recorded that no EAL had been met
1355	Eight individuals transported to Central Facilities Area Medical
1405	MFC EAM declared discretionary OE INL-ALL-DICH.OG.1 MFC getting CWI radcon support.
1406	EOC operational (full activation)
1415	DOE-HQ EOC to provide initial notification
1435	Bridge call MFC- CWI radcon will be performing airborne rad surveys. No information on initial 4 facial c/. ED directed all affected facilities be evacuated.
1441	EAM announce the all call for all individuals to evacuate 774 and relocate to 725.
1443	FMF/ZPPR NFM confirmed that 17 people being transported to CFA for 'survey' 'surveys' started at 14:30 and take 1 hr each.

Time (MST)	Log Entry
1436	First person sent to CFA for whole body counts
1458	DOE Facility Representative located at MFC explained clamshell opened and a bag contained ^{239}Pu fuel was cut open. Loose powder observed, smeared and walked across room to a counting station. RT said it's too hot and need to evacuate. CAM alarm received. Clamshell closed by replacing the lid toward the worker. It is believed that the 2 screws are not engaged to tighten the clamshell.
1515	Bridge call MFC EAM-17 total people sent to CFA, 6 positive nasal counts. A Radiation Technician had a minor knee injury also sent to CFA medical. CWI airborne samples being counted and results need another 15 min. Need to reenter EML to control equipment (N2 dewars and secure ion gun) and retrieve employees' personal effects.
1518	Completed consequence assessment form per EOC request
1558	Airborne surveys, both internal and external to the building are negative (not including Vault).
1600	Bridge call MFC-coordinating shuttling people back from medical.
1626	Contacted DOE-ID Manager and the acting Deputy Manager for Nuclear Energy
1824	Called DOE-HQ-EOC to advise EOC is stood down.
1830	Secured MDO watch

Analysis

The absence of an EAL for this accident scenario required the use of a discretionary EAL and resulted in hesitation on the part of the EDs and MFC EAM to declare an OE and fully activate the ECC and EOC.

The lack of procedural guidance for a partial activation of the ERO contributed to a delay in fully staffing the ERO, which in turn resulted in an inability to fully coordinate and resource the response. Therefore, essentially no ERO assistance was available until after the affected individuals had been decontaminated and had been prepared for transportation to CFA Medical.

The initial event was managed almost entirely by the MFC radiological control and operations organizations. A timely response by the ERO could have brought in additional resources, such as Radiological Control personnel from other facilities and emergency medical technicians from the INL Fire Department, which could have provided for a more timely egress and monitoring of personnel, in addition to more timely and extensive monitoring outside the building.

Additionally, the Board's review of MFC drill scenarios for 2010 and 2011 indicated that only one radiological drill had been performed at MFC during that two-year period. There was no evidence of a drill that would have prepared the workforce to respond to an event involving multiple contaminated personnel who required transport to CFA. Medical and radiological staff stated that no drills have been performed that would have prepared them for recognizing and responding to the emotional trauma of such an event and securing aid from the employee assistance program.

> The Board concluded that the BEA emergency management program did not sufficiently coordinate a timely response to the ZPPR operational emergency. **[JON 15, JON 16]**

2.4.5.1. Radiological Emergency Response

Vault CAM Alarm and Response

The fixed position Vault CAM in the Workroom is located approximately 15 feet from the work area in front of the Shipping Hood and monitors air flow from the adjacent Vault area. (A portable CAM located on the north side of the Shipping Hood was not made operable for the job evolution.) The fixed position Vault CAM monitors alpha airborne radioactivity concentrations and provides two response capabilities. The fast response compares the latest DAC reading with the reading from five minutes previous, to account for background readings, and is set to alarm at a reading of an increase of 500 DAC. The slow response compares the latest DAC reading with the reading from 60 minutes previous, to account for background readings and expected fluctuations in radon concentrations, and is set to alarm at a reading of an increase of 8 DAC. Vault CAM readings are recorded every minute.

The Vault CAM in the Workroom has an alarm indicator in the Control Room, which has no separate CAM or monitoring.

At 1107, the Vault CAM recording shows an increase in the Vault CAM readings. According to the video recording of the event, between 1107 and 1108, the Vault CAM alarmed on the fast response. The 1109 Vault CAM recording for the fast alarm was 791 DAC. The fast response reading peaked at 1906 DAC. The slow response peaked at 1211 at 223 DAC. The Vault CAM recording also shows that between 1205 and 1209, the slow response readings rose, with a peak reading of 4657 DAC. Shortly before this time, the building supply fans were secured resulting in a slight increase in the Vault CAM recording results.

Following the Vault CAM alarm and evacuation from the Workroom, HPT-3 was asked to assist in responding to a "spill" in the Workroom by bringing a radiation meter to the Control Room. HPT-3 was not wearing PPE, and subsequently HPT-3's shoes became contaminated. In addition, 12 or more HPTs from other MFC facilities provided radiological response and established a series of four decontamination and monitoring stations to facilitate the evacuation of the 16 affected individuals from the Control Room. Ten of the individuals were successfully decontaminated at ZPPR. Six of the individuals were transported to EBR-II, located at the MFC, for decontamination.

At approximately 1215, CFA Medical was informed of a Pu incident at MFC involving “a lot of people.” CFA Medical requested that an HPT accompany the individuals and provide radiological monitoring of the individuals and the medical facility. At 1220, CFA Medical contacted the Acting Site Occupational Medicine Director (SOMD) and informed him of the situation. The Acting SOMD called Radiation Emergency Assistance Center/Training Site (REAC/TS) and requested their team activation.

At approximately 1320, CFA Medical personnel requested support from CFA Fire Station 1 in anticipation of a reported 17 decontaminated individuals needing chelation. Four firefighters helped set up patient beds and provided logistics support throughout the afternoon and evening.

At approximately 1340, a conference call was held involving BEA, Radiological Control and Medical representatives, and REAC/TS staff. REAC/TS documented their understanding of information in an internal e-mail, which stated that they were informed of the following:

- There was a hood release of mostly ^{239}Pu affecting 15 individuals.
- The affected room, with eight individuals, has over 200 DAC.
- The adjacent room, with seven individuals, has 97 DAC.
- Evacuation time was 5 to 10 minutes.
- The highest nasal smear was 150 dpm.
- No respiratory protection was worn.

No additional information on radiation dose potential was provided. BEA Medical staff had a similar understanding of the radiological conditions.

REAC/TS advised that despite the relatively low nasal smears and not having been provided dose assessment information from Radiological Control, chelation should be started on all affected individuals (i.e., individuals in both rooms) as soon as possible and that bioassay sampling (urine and fecal) should be initiated. REAC/TS stated that they would provide additional chelation material.

Analysis

REAC/TS and CFA Medical were given incorrect information regarding airborne contamination levels, the areas being monitored by CAMs, and CAM alarms. As a result, REAC/TS and CFA Medical personnel believed that a CAM was monitoring the Control Room and indicated 97 DAC. Discussions with BEA staff and review of critiques indicated insufficient knowledge of how to interpret Vault CAM readings.

The information provided to REAC/TS and CFA Medical also was not sufficient to assess the need for medical intervention. TEV-500, *Technical Evaluation for Establishing Levels of Radionuclide Intakes for Consideration of Medical Intervention*, provides the basis and guidance for recommending medical intervention following a radiological exposure. It states that the Radiological Control staff should provide the physician with information about the radionuclide(s), their chemical form and solubility class, and the dose consequences of not performing a treatment. Radiological Control informed the medical staff that the material was Pu but did not provide additional information.

The Board concluded that Radiological Control personnel had inadequate training that did not allow them to evaluate facility radiation monitor data and did not ensure that they could communicate this information accurately. **[JON 12]**

Decontamination and Chelation

The accident resulted in the contamination of all 16 affected individuals. The external contamination levels ranged from 600 cpm on the head and hand of one individual down to non-detectable. The six individuals with the highest nasal smear results (overall results ranged from 3 to 289 dpm) were sent to CFA Medical for chelation; only four of these individuals opted for chelation. The ten individuals who had lower nasal smear results were sent to the lung counting facility and were also offered the option of chelation. One individual stated that he did not recollect being offered chelation.

The first individuals to be chelated arrived at CFA Medical without an accompanying HPT to perform radiological monitoring as requested by CFA Medical staff. An HPT arrived at CFA Medical to monitor the individuals and the CFA Medical area one to two hours later.

BEA had chelation material available for 15 chelation applications, 10 with Ca-DTPA (pentetic acid) and 5 with Zn-DTPA. Ca-DTPA is preferred for initial chelation unless a medical condition, such as kidney problems or pregnancy, requires use of Zn-DTPA. In the past, 45 chelation applications were locally available (three sets of 15). However, due to an increase in the cost of the chelation material and REAC/TS's budget constraints, REAC/TS was only able to provide one set of 15 chelate applications to BEA, which was kept at CFA Medical.

Additional Zn-DTPA chelation doses arrived at the site from REAC/TS on November 9, 2011. REAC/TS personnel stated that only Zn-DTPA was available at that time.

Analysis

BEA had sufficient material to chelate, with the preferred chelate, for 10 initial chelations. This supply was adequate to provide chelate for this accident. However, an accident scenario involving more individuals needing chelation or if more of the affected individuals chose to have chelation, the supply would have not been sufficient.

The Board concluded that the amount of chelate kept on hand was not based on accident scenarios. **[JON 17]**

2.4.5.2. Bioassay Sample Collection

During the afternoon and evening of November 8, 2011, all 16 affected individuals were lung counted for 30 minutes in the lung counter. Two individuals had positive results, 0.73 and 1.3 nCi ^{241}Am. The subsequent day's counting results were 0.41 nCi ^{241}Am (a 40% decrease) for one of these individuals and no detectable activity for the other.

TPR-6743, *Incident Related to In Vivo Counting,* Section 4.4, specifies that personnel are to shower before having a special count, but the individuals who had positive lung count results had not showered before counting. The rapid decrease in results following the initial counts indicates that at least part of the initial positive ^{241}Am count results could have been due to low-level external contamination remaining on the individual.

BEA does not have procedures or a written technical basis document for assessing positive lung count results in terms of radiation dose. TEV-500 has information on evaluating the magnitude of potential radiation dose based on nasal smear results, but there is no evidence that this information was used or otherwise considered during this accident response. In addition, TEV-500 notes that ICRP 66, *Human Respiratory Model for Radiological Protection*, discusses the efficacy of nose blowing in removing deposition in the nasal region; however, discussions with affected individuals indicated that this action was not performed. Furthermore, the BEA lead health physicist for internal dosimetry did not have information on the composition of the source term involved in the accident. On the afternoon and evening of the accident, the BEA staff was researching source term data to develop a process for evaluating radiation doses.

Table 2-2 in Section 2.4.1 of this report illustrates the isotopic composition of one of the Pu fuel plates calculated from an initial 1983 isotopic content evaluation. The isotopic estimate developed by the BEA internal dosimetry lead health physicist after the accident was generally consistent with Table 2-2 for several isotopes, but the assumptions about the quantities of ^{241}Am and ^{241}Pu differed from those made in the 1983 estimate. BEA also provided the Board an assessment of isotopic data on the clamshell contents; however, this assessment was based on decay calculations for an18-year period (i.e., since the 1983 evaluation) instead of a 28.3-year period (i.e., over the life of the fuel plate). Table 2-2 also shows that ^{241}Am is expected to contribute approximately 30% of the total whole body dose for a medium-absorption material, which would be the type of material resulting in the highest dose. BEA had not evaluated the dose contributions of the isotopes in the fuel plate before the November 8, 2011, accident.

Bioassay sample collection (urine and fecal) was initiated for all 16 individuals on November 8, 2011. The six individuals with the highest nasal smear results were asked to provide daily fecal and urine samples. The other individuals were asked to provide samples on November 9, 2011, and then again November 11, 18, and 21, 2011. After the first week following the accident, the sampling interval was decreased for the six individuals with the highest nasal smear results to be consistent with the others.

An offsite laboratory under contract provided support in analyzing the bioassay results. Site personnel stated that due to miscommunication with the offsite laboratory, the first samples sent were not properly handled. The fact that they were post-chelation samples was not taken into account and the results were not properly analyzed. Because communications with the laboratory were verbal, the cause of the miscommunication could not be determined. This error was corrected for subsequent sample analyses.

On November 9, 2011, a second chelation was offered to the individuals with initial positive lung count results. Both individuals declined chelation at that time. Three out of the four individuals having chelation developed flu-like symptoms, including loss of appetite and diarrhea.

Analysis

Requiring personnel to shower before lung counting likely would have allowed a quicker assessment of the magnitude of the dose. Site personnel stated that one of the reasons they did not provide showers for the personnel undergoing decontamination was an insufficient supply of hot water at the lung counting facility. If the nearby CFA Medical facility showers had been used, the initial lung count results would likely have been a better indicator of the magnitude of the intakes.

While TEV-500 provides guidance on evaluating nasal smear results, there is no other guidance on quickly evaluating lung count results. There was evidence of insufficient knowledge of radiological isotopic content and the physical properties of the radioactive material present for use in evaluating radiological monitoring data.

Better communication with the offsite laboratory regarding the status of the bioassay samples and the requested type of analysis could have allowed the initial samples to be analyzed properly and could have avoided a delay in evaluating the radiological impacts of the accident.

The Board concluded that BEA does not have a process in place to promptly assess intakes of radioactive material for use in internal dose assessments and medical response to radiological emergencies. **[JON 18]**

The Board concluded that BEA does not have an effective program for training cognizant personnel on certain radiological response activities (e.g., showering before special lung counts, nose blowing) and communicating radiological information (e.g., information concerning bioassay samples). **[JON 15, JON 18]**

2.4.5.3. MFC Management Response to the Event

At approximately 1630, BEA Radiological Control management arrived at the CFA-690 WBC Facility. The affected individuals expressed concern about their potential exposures and possible side effects of chelation. MFC Operations management arrived at the WBC Facility at approximately 1800 to initiate fact finding, which was initially conducted in a room associated with the whole body counter. However, to help ensure the affected individuals' privacy, the fact-finding meeting was moved to a more private medical facility conference room. During this investigation, several employees expressed to the Board their concern that the decision to interview individuals while they were still being treated and evaluated was inappropriate. BEA conducted a formal fact-finding critique on November 9, 2011.

During the first week after the event, the affected workers were offered counseling sessions with Radiological Control and Medical staff. Initially, those were group sessions, but because some individuals did not feel comfortable in the group environment, they did not share or receive answers for their concerns. These individuals eventually approached management and expressed their worries and dissatisfaction. Management expressed their regret at not responding to the needs of the affected individuals in an appropriately sensitive manner and began offering one-on-one counseling sessions with medical and dosimetry professionals.

During the investigation, the Board noted that the affected workers experienced significant stress resulting from remorse at not having been able to prevent the accident, anxiety over not understanding their medical treatment and options, and concerns about the long-term consequences of their contamination. In some cases, their stress appropriately prompted support from the employee assistance program.

The Board recognizes the need to balance timely information-gathering in an emergency with respect for the privacy of medical information and professional counseling. The Board encourages BEA to establish guidelines and conduct training and drills to address these interconnected emergency response needs.

2.4.5.4. Preliminary Worker Dose Estimate

The radiological dose assessment will take several months to complete because many bioassay samples will be needed over time to assess the retention of the radioactive material in the body. DOE-STD-1121-2008, *Internal Dosimetry*, Section 5.4 recognizes this and states:

> *Thus, multiple bioassay measurements over several days following an intake provide a better tool for quantifying the magnitude than a single sample. These may include longer term measurements at weeks, months, and even years after an intake to accurately characterize the biokinetics and provide accurate intake and dose assessments.*

DOE-STD-1121-2008 also discusses the extremely conservative nature of initial dose estimates and states in Section 9.2:

> *It will not be unusual for a preliminary assessment of 10 or 20 rem CEDE* [committed effective dose equivalent] *derived from initial bioassay data for a plutonium intake to ultimately be lowered to 1 rem CEDE based on long-term follow-up data.*

Early in the accident investigation, the Board reviewed the initial results that were available for nine of the individuals, including the individuals with the highest nasal smear results. The Board independently reviewed these preliminary bioassay results and derived dose consequence values. The Board also used intake retention functions from DOE-STD-1128-2008 and DAC values from 10 CFR 835, Appendix A, to evaluate the potential intakes and upper estimates of doses to the affected individuals. The 10 CFR 835 applicable dose limits are 50 rem committed equivalent dose to the bone surface and 5 rem committed effective dose to the whole body.

The Board results indicate intakes ranging from approximately 0 to 5 times the annual limit on intake. Intakes of this magnitude correspond to doses ranging from 0 to 250 rem committed equivalent dose to the bone surface (approximately 0 to 8 rem committed effective dose to the whole body). These preliminary evaluations are based on the limited data available during the early portion of the accident investigation. Although no bounding errors were calculated for these evaluations, the Board believes that the range stated above encompasses the probable dose consequences of the accident, especially when the effects of chelation are determined by future bioassay analysis.

After the onsite phase of the Board’s investigation, BEA continued receiving initial results of bioassay sample analysis. These results are still being confirmed by BEA. As of December 16, 2011, BEA’s preliminary estimates of dose consequences from the accident for the affected individuals are summarized below:

- Half of the group (eight individuals) is likely to have low-level intakes assigned as indicated by negative lung count results and low-level fecal results. Doses for these individuals may ultimately be reported as zero if the committed effective dose is determined to be less than 10 mrem (see 10 CFR 835.702(b)).
- The best estimate of the bounding committed effective dose is less than 2.1 rem (counting uncertainties range between 0 and 7.5 rem).
- The best estimate of the bounding committed equivalent dose (to bone surfaces) is less than 71 rem (counting uncertainties range between 0 and 257 rem). Based on the best estimates of bounding doses, two individuals have the potential of exceeding the 50 rem annual limit to an individual organ/tissue.

The Board discussed with BEA their approach to evaluating bioassay results for dose assessment. The Board determined that the combination of the bioassay sampling as implemented and plans for dose assessment methodology provides reasonable assurance that BEA will accurately assess the radiological consequences of the accident.

Given the range of uncertainty previously discussed in DOE-STD-1121-2008, the Board concluded that BEA's initial evaluation of the dose consequences of the accident was reasonable.

Dose estimates will be refined as additional bioassay monitoring and radiochemical analysis of air samples and workplace smears become available. The Board cautions that the estimates reported here are preliminary dose estimates and should not be assumed to be the final doses to the workers.

2.5. Integrated Safety Management Implementation

DOE M&O contractors are required to implement a Safety Management System in accordance with 48 CFR 970.5223-1, *Integration of Environment, Safety, and Health into Work Planning and Execution*. The requirement states that in performing work, the contractor shall perform work safely, in a manner that ensures adequate protection for employees, the public, and the environment, and shall be accountable for the safe performance of work. The contractor shall exercise a degree of care commensurate with the work and the associated hazards. The contractor shall ensure that management of ES&H functions and activities becomes an integral but visible part of the contractor's work planning and execution processes. This contract clause identifies the guiding principles and core functions that are expected to be integrated into the work planning and execution processes. Those expectations are reviewed in this section.

2.5.1. Guiding Principles (GP)

The guiding principles are the fundamental policies that guide DOE and contractor actions, from development of safety directives to performance of work. The Board's review of evidence related to this accident identified the following facts related to the guiding principles. Each bulleted item provides a reference to the relevant section(s) of this report.

Line Management Responsibility for Safety (GP-1)

Line management is directly responsible for the protection of employees, the public, and the environment. Line management includes those Contractor and subcontractor employees managing or supervising employees performing work.

- DOE-ID's responsibilities for conducting an independent review of the technical assumptions in the ZPPR safety basis are not well understood. (Section 2.4.2, Safety Basis)

- BEA management systems were not effective in communicating the risk of failed Pu fuel plates so that the need to enter the USQ process could be evaluated. (Section 2.4.2, Safety Basis)

Clear Roles and Responsibilities (GP-2)

Clear and unambiguous lines of authority and responsibility for ensuring safety are established and maintained at all organizational levels within the Department and its contractors.

- The roles, responsibilities, and authorities of the MFC ISRC are defined but were not effectively executed with respect to the ZPPR Facility. (Section 2.4.2.3, Safety SSCs and Passive Design Features – Pu Fuel Plate)
- Authority was given to the SS alone to decide how to proceed with the packaging operation after the discovery of an abnormal condition. (Section 2.4.3.1, Work Management Process and Section 2.4.3.4, Execution of Work)

Competence Commensurate with Responsibly (GP-3)

Personnel possess the experience, knowledge, skills, and abilities that are necessary to discharge their responsibilities.

- The facility workers were not afforded the necessary experience, knowledge, skills, and abilities to recognize the hazards and necessary controls for Pu reactor fuel handling. (Section 2.4.3.5, Training Qualification and Proficiency)
- Training did not provide emergency response personnel with the necessary experience, knowledge, skills, and abilities to evaluate and communicate facility radiation monitor data. (Section 2.4.5.1, Radiological Emergency Response)

Balanced Priorities (GP-4)

Resources are effectively allocated to address safety, programmatic, and operational considerations. Protecting the workers, the public, and the environment is a priority whenever activities are planned and performed.

- The facility safety basis determined that no engineered controls were safety significant, and instead relied on defense-in-depth SSCs; a glovebox was not deemed to be needed. (Section 2.4.2.4, Defense-in-Depth SSCs – Hoods and Section 2.4.2.5, Defense-in-Depth SSCs – Radiation Monitoring System)

Identification of Safety Standards and Requirements (GP-5)

Before work is performed, the associated hazards are evaluated and an agreed upon set of safety standards and requirements are established which, if properly implemented, provide adequate assurance that workers, the public, and the environment are protected from adverse consequences.

- The guidance of DOE-STD-1128-2008, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities*, could have provided insights for safer Pu handling practices. (Section 2.4.2.4, Defense-in-Depth SSCs – Hoods)

Hazard Controls Tailored to the Work Being Performed (GP-6)

Administrative and engineering controls to prevent and mitigate hazards are tailored to the work being performed and associated hazards.

- The use of a PWS for the packaging activity, rather than the LWP-21220 procedure, created work steps that did not have a corresponding hazard analysis or accompanying mitigation for loading the material into containers. (Section 2.4.3.1, Work Management Process)

Operations Authorization (GP-7)

The conditions and requirements to be satisfied for operations to be initiated and conducted are established and agreed-upon.

- The long delays in upgrading the ZPPR safety basis and years of reliance on a BIO resulted in an acceptance of the risk of continuing operation. (Section 2.4.2, Safety Basis)

2.5.2. Core Functions (CF)

The five core safety management functions provide the necessary structure for any work activity that could potentially affect the public, the workers, and the environment. The functions are applied as a continuous cycle with the degree of rigor appropriate to address the type of work activity and the hazards involved.

The Board identified deficiencies in the work planning and control activities associated with each of the five core functions.

Define the Scope of Work (CF-1)

Missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.

- The work activity for packaging the Pu fuel plates did not identify the historical practices for managing suspect fuel.

Identify and Analyze the Hazards Associated with the Work (CF-2)

Hazards associated with the work are identified, analyzed, and categorized.

- The work activity did not anticipate the damaged fuel plate and potential for the release of contaminants.

Develop and Implement Hazard Controls (CF-3)

Applicable safety standards and requirements are identified and agreed upon, controls to prevent/mitigate hazards are identified, the safety envelope is established, and controls are implemented.

- DOE-STD-1128-2008 was not used for planning the work activity.
- The safety basis did not identify the need for the work to be conducted in the glovebox.

Perform Work within Controls (CF-4)

Readiness is confirmed and work is performed safety.

- The procedures did not clearly define points when work was to stop if an abnormal condition was encountered.
- The management systems supporting the decision to continue to work did not require the SS and NFM to consult with subject matter experts and those familiar with historical facility operations.
- The workers proceeded to cut the bag on the damaged fuel plate without a procedure step and associated hazard controls in place to do so.

Provide Feedback on Adequacy of Controls and Continue to Improve Safety Management (CF-5)

Feedback information on the adequacy of controls is gathered; opportunities for improving the definition and planning of work are identified and implemented.

- Multiple opportunities were missed to identify the hazards and risks associated with packaging Pu fuel plates of unknown integrity.

2.6. Accident Analysis

2.6.1. Events and Causal Factors Chart

After performing the barrier and change analyses, the Board assigned the results of the various analyses to the conditions that were related to or caused the events in the chronology. Correlating these conditions with events resulted in the events and causal factors chart provided in Appendix E. When the correlation was complete, the Board examined the chart to determine which events were significant (i.e., which events played a role in causing the accident).

The Board then assessed the significant events (and the conditions of each) to determine the causal factors of the accident.

Direct, Root, and Contributing Causes

The Board determined that this accident was preventable.

The Board determined that the **direct cause** of the accident was the cutting and handling of the plastic wrapping around the Pu fuel plate, which released the Pu contaminants.

Root causes are the causal factor(s) that, if corrected, would prevent recurrence of the same (local) or similar (systemic) accidents. The Board determined that the **local root causes** were:

- BEA did not accurately analyze the Pu hazard in the safety basis and establish commensurate controls.
- The management system lacked requirements intended to influence the decision making of the NFM and SS, resulting in a single-point decision to cut the wrapping.

The Board determined the following **systemic root causes**:

- DOE-ID accepted the risk of known safety basis deficiencies and allowed continued operation of the ZPPR Facility within the framework of a multi-year safety basis upgrade plan without putting effective interim controls in place.
- BEA continued operation of the ZPPR Facility with known safety basis deficiencies and without adequately analyzing the hazard to the worker or establishing effective work control processes.

Contributing Causes

Contributing causes are events or conditions that collectively with other causes increased the likelihood of the accident but that individually did not cause the accident. The Board identified three contributing causes to this accident:

1. The organizational transition resulted in a loss of knowledge and past practices and records that indicated the conditions associated with the fuel plates.

2. Senior MFC management did not recognize the significance of information provided by the history of Pu fuel plate failures and by the MFC ISRC Chairman's white paper.

3. The PWS used to conduct the work did not contain directions governed by any of the referenced operating instructions, leading to the creation of work steps without an appropriate hazard analysis or accompanying means of mitigation.

2.6.2. Barrier Analysis

After a basic chronology of events was developed, the Board performed a barrier analysis of the accident. To start the barrier analysis, the Board chose a target (the person or item to be protected) and the hazard (what the person or item is to be protected from). The Board chose workers and facilities as the target and transuranic material as the hazard. Thirteen barriers were identified and analyzed by the Board.

The barrier analysis is presented in Appendix B.

2.6.3. Change Analysis

To further support the development of causal factors, the Board performed a change analysis of the accident, examining the planned and unplanned changes that caused the undesired results or outcomes related to the event.

The change analysis is presented in Appendix C.

2.6.4. Human Performance Improvement

Human performance improvement (HPI) is about reducing errors and managing defenses to prevent significant events. The application of HPI principles in numerous organizations (medical, nuclear, chemical, etc.) has resulted in improved safety, quality, and productivity. HPI is not a program, but rather a distinct way of thinking based on a performance model that illustrates the organizational context of human performance.

HUMAN PERFORMANCE ATTRIBUTES

Task Demands. Specific mental, physical and team requirements to perform an activity that may either exceed the capabilities or challenge the limitations of human nature of the individual assigned to the task; for example, excessive workload, hurrying, concurrent actions, unclear roles and responsibilities, or vague standards.

Individual Capabilities. Unique mental, physical, and emotional abilities of a particular person that fail to match the demands of the specific task; for example, unfamiliarity with the task, unsafe attitudes, level of education, lack of knowledge, unpracticed skills, personality, inexperience, health and fitness, poor communication practices, or low self-esteem.

Work Environment. General influences of the workplace, organization, and cultural conditions that affect individual behavior; for example, distractions, awkward equipment layout, complex tagout procedures, at-risk norms and values, work group attitudes toward various hazards, or work control processes.

Human Nature. Generic traits, dispositions, and limitations of being human that might incline individuals to err under favorable conditions; for example, habit, short-term memory, fatigue, stress, complacency, or mental short cuts.

DOE-HDBK-1028-2009, *Human Performance and Improvement Handbook Volumes 1 and 2,* describes the HPI tools available for use at DOE sites. For the purposes of this investigation, the Board looked at certain aspects of HPI, such as error precursors, as they may have contributed to the causal factors of the accident. Error precursor analysis identifies the specific error precursors that were in existence at the time of or prior to the accident. Error precursors are unfavorable factors or conditions embedded in the job environment that increase the chances of error during the performance of a specific task by a particular individual or group of individuals. Error precursors create an error-likely situation that typically exists when the demands of the task exceed the capabilities of the individual or when work conditions aggravate the limitations of human nature. A review of human performance is a review of individual abilities, tasks, and operating environment to determine whether the organization supported individuals in achieving a successful outcome.

The Board's human performance analysis is presented in Appendix D.

3.0 Conclusions and Judgments of Need

JONs are the managerial controls and safety measures determined by the Board to be necessary to prevent or minimize the probability or severity of a recurrence. These JONs are linked directly to the causal factors derived from the facts and analysis. They form the basis for CAPs, which must be developed by line management. The Board's conclusions and JONs are listed in Table 3-1.

Table 3-1. Conclusions and Judgments of Need

Conclusion	Judgments of Need
Safety Basis	
The Board concluded that the DOE-ID and BEA oversight systems were not managed in such a way that they could readily identify and correct legacy deficiencies in the technical bases supporting the ZPPR safety basis. **[JON 1, JON 3]**	JON 1: BEA needs to validate the technical bases used to support the safety and design basis of the ZPPR Facility, including a reassessment of the likelihood, severity, and risk of accidents and the effectiveness of hazard controls.
The Board concluded that BEA failed to recognize the significance of and take appropriate action in response to available information regarding the material condition of Pu fuel plates. **[JON 1, JON 2]**	JON 2: BEA needs to evaluate and revise the PISA and unreviewed safety question (USQ) processes to ensure that they are implemented and applied by facility management when new information is discovered that affects the safety basis of nuclear facilities.
The Board concluded that actual Pu fuel plate failures were not reviewed in the appropriate context to lead to changing the observed failure rate as stated in the safety basis. As a result, workers were at increased risk of exposure to uncontrolled radioactive material. **[JON 2]**	JON 3: DOE-ID needs to utilize all necessary resources to confirm the validity of ZPPR Facility safety basis assumptions prior to the resumption of fuel handling other than for recovery from this accident.
The Board concluded that the ZPPR Facility safety basis does not quantify credit associated with the ZPPR Workroom South Hood for mitigating accidental releases of radioactive material, nor does it provide technical bases for qualifying the Workroom South Hood as a defense-in-depth SSC. **[JON 4]**	JON 4: BEA needs to provide technical justification to DOE-ID and receive approval prior to performing plutonium fuel handling operations outside of a glovebox.
The Board concluded that, though credited in the ZPPR safety basis for defense-in-depth, the ZPPR Workroom South Hood was not maintained in such a way to provide assurance of its performance or operability. **[JON 5]**	JON 5: BEA needs to ensure that their nuclear facility maintenance program maintains equipment as credited in the documented safety analyses.

Conclusion	Judgments of Need
Work Planning and Control	
The Board concluded that the use of a PWS for the packaging activity was not consistent with the BEA procedure development process as defined by LWP-21220. **[JON 6]**	JON 6: BEA needs to use LWP-21220 generated procedures instead of process worksheets to direct work.
The Board concluded that the planning effort did not include a thorough review of available historical data to assist in the work planning process. **[JON 7]**	JON 7: BEA needs to strengthen execution of the work planning process to ensure that a thorough review of available historical resources and lessons learned is conducted in order to accurately determine the scope of work.
The Board concluded that the evaluation points and limiting conditions developed by the As Low As Reasonably Achievable (ALARA) review and required by the RWP were insufficient to result in stopping work and re-evaluating the hazards when unanalyzed/unexpected hazards transpired. **[JON 8]**	JON 8: BEA needs to ensure that ALARA reviews and RWPs address actions to be taken when abnormal conditions are encountered.
The Board concluded that although the Vault CAM alarmed in response to the event as designed, its placement, as determined in engineering evaluations, was not optimal for the work being performed in the Workroom hood. **[JON 9]**	JON 9: BEA needs to evaluate its program for establishing the placement of air monitoring equipment to provide workers with early indication of a radiological hazard.
Execution of Work	
The Board concluded that the work group failed to realize that the additional steps to cut the wrapping material from the fuel plate were outside the boundaries of the RWP and should have resulted in stopping work. **[JON 10]** The Board concluded that the work group performed operations to cut the wrapping material from the fuel plate without an approved procedure step to direct the action. **[JON 10]**	JON 10: BEA needs to reinforce the expectation that if a procedure cannot be performed as written, work should stop.
The Board concluded the training provided by MFC00027 and other training experiences did not inform the workers adequately to alert them to stop working when they encountered the abnormal condition of multiple wraps of plastic and red tape after opening the clamshell. **[JON 11]** The Board concluded that training of MFC employees was not effective in providing the workers with the knowledge needed to recognize that a visible quantity of Pu particulate represented a hazard warranting immediate evacuation. **[JON 11]**	JON 11: BEA needs to provide comprehensive facility-specific plutonium hazards training that maintains the proficiency of all managers, supervisors, and workers in recognizing unique hazards associated with working with plutonium.
The Board concluded that Radiological Control personnel had inadequate training that did not allow them to evaluate facility radiation monitor data and did not ensure that they could communicate this information accurately. **[JON 12]**	JON 12: BEA needs to provide training to the radiological control personnel on evaluating facility radiation monitor data and communicating this information accurately.

Conclusion	Judgments of Need
DOE Oversight The Board concluded that DOE-ID's field oversight at MFC has been appropriately balanced and effective in identifying weaknesses in contractor performance and communicating them to management.	No JON needed.
BEA Oversight The Board concluded that although there has been a noticeable increase in the number of self-assessments conducted at MFC, they lack the quality and depth needed to consistently identify and correct issues that significantly improve performance. **[JON 13, JON 14]**	JON 13: BEA must apply a concerted effort in the planning for and field observance of work activities at MFC until measureable improvement is attained. JON 14: BEA needs to provide mentoring and direction for MFC personnel conducting oversight activities in the field to improve identification of deficiencies.
Emergency Management The Board concluded that the BEA emergency management program did not sufficiently coordinate a timely response to the ZPPR operational emergency. **[JON 15, JON 16]** The Board concluded that the amount of chelate kept on hand was not based on accident scenarios. **[JON 17]** The Board concluded that BEA does not have a process in place to promptly assess intakes of radioactive material for use in internal dose assessments and medical response to radiological emergencies. **[JON 18]** The Board concluded that BEA does not have an effective program for training cognizant personnel on certain radiological response activities (e.g., showering before special lung counts, nose blowing) and communicating radiological information (e.g., information concerning bioassay samples). **[JON 15, JON 18]**	JON 15: BEA needs to develop and implement training on radiological response, including drills, exercises, and evaluation of radiological consequences of accidents. JON 16: BEA needs to reassess the hazards assessments at the ZPPR Facility and incorporate the results into the emergency management program. JON 17: BEA needs to evaluate the adequacy of the local availability of chelating material at INL facilities. JON 18: BEA needs improve processes that are used to identify radiological source term information for use in evaluating and responding to radiological emergencies.

4.0 Board Signatures

Charles B. Lewis III
DOE Accident Investigation Board Chairperson
U.S. Department of Energy
Office of Health, Safety and Security, HS-23

Aleem E. Boatright
DOE Accident Investigator and Board Member
U.S. Department of Energy
Office of Health, Safety and Security, HS-45

Roger M. Claycomb
DOE Accident Investigator and Board Member
U.S. Department of Energy
Idaho Operations Office, DOE-ID

Steven R. Ahrendts
DOE Accident Investigator and Board Member
U.S. Department of Energy
Idaho Operations Office, DOE-ID

5.0 Board Members, Advisors and Consultants

Board Members

Chairperson	Charles B. Lewis III, Chair, HS-23
Accident Investigator	Aleem Boatright, Investigator/Board Member, HS-45
Member	Roger M. Claycomb, Investigator/Board Member, DOE-ID
Member	Steven R. Ahrendts, Investigator/Board Member, DOE-ID

Advisor/Team Coordinator

Advisor	Tauna Butler, Advisor/Health Physics, DOE-ID
Investigator	Peter O'Connell, Investigator, HS-11
Accident Analyst/Coordinator	William McQuiston, MAS Consultants
Consultant/Advisor	Robert C. Seal, MAS Consultants

Administrative Coordinator

Administrative Support	Susan M. Keffer, Project Enhancement Corporation
Technical Editor	Kathy Moore, Unwin

Appendix A: Appointment of an Accident Investigation Board

Department of Energy
Washington, DC 20585

November 10, 2011

MEMORANDUM FOR CHARLES B. LEWIS III
BOARD CHAIRPERSON
DIRECTOR
OFFICE OF CORPORATE SAFETY PROGRAMS

FROM: GLENN S. PODONSKY
APPOINTING OFFICIAL
CHIEF HEALTH, SAFETY AND SECURITY OFFICER

SUBJECT: Accident Investigation into the Plutonium Contamination and Personnel Exposures at the Materials and Fuels Complex at the Idaho National Laboratory on November 8, 2011

The Office of Nuclear Energy (NE) has requested that the Office of Health Safety and Security (HSS), in accordance with the requirements of Department of Energy (DOE) Order 225.1B, *Accident Investigations*, establish an Accident Investigation Board (AIB) to investigate the Plutonium Contamination and Personnel Exposures at the Materials and Fuels Complex at the Idaho National Laboratory, on November 8, 2011.

You are appointed as the Board Chairperson. The Board will be composed of the following members and advisors:

- Aleem Boatright - Board Member, Accident Investigator, Office of Safety and Emergency Management Evaluations (HS-45)
- Roger Claycomb - Board Member, Office of Nuclear Energy (NE-ID)
- Steve Ahrendts - Board Member, Office of Nuclear Energy (NE-ID)
- Tauna Butler - Advisor - Health Physics, Office of Nuclear Energy (NE-ID)
- William McQuiston - Accident Analyst/Coordinator
- Robert Seal - Consultant Advisor
- Susan Keffer - Administrative Support

This appointment is based on a joint determination whereby NE believes it is in the best interest of the Department that HSS conduct the investigation.

All members of the AIB, by this letter, and in accordance with the requirements of DOE Order 225.1B, are released from their normal regular duty assignment to serve on the AIB during the period the AIB is convened.

The scope of the Board's investigation is to include, but not be limited to, identifying all relevant facts, determining direct, contributing, and root causes of the event, developing conclusions, and determining the judgments of need to prevent recurrence. Also, the scope of the investigation is to include Department of Energy's programs and oversight activities.

The Board is expected to provide my office with periodic reports on the status of the investigation. Please submit draft copies of the factual portion of the investigation report to me, NE, and the affected contractor for factual accuracy review prior to finalization. The final report should be provided to me no later than 30 days of the date of this memorandum. Discussion of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

cc: Peter B. Lyons, NE-1
Dennis Miotla, NE-3
Robert Stallman, NE-ID

Appendix B: Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any means used to control, prevent, or impede a hazard from reaching a target, thereby reducing the severity of the resultant accident or adverse consequence. A hazard is the potential for an unwanted condition to result in an accident or other adverse consequence. A target is a person or object that a hazard may damage, injure, or fatally harm. Barrier analysis determines how a hazard overcomes the barriers, comes into contact with a target (e.g., from the barriers or controls not being in place, not being used properly, or failing), and leads to an accident or adverse consequence. The results of the barrier analysis are used to support the development of causal factors.

Table B-1. Barrier Analysis

Hazard: Transuranic Material		**Target: Workers & Facility**	
What Were the Barriers?	**How Did Each Barrier Perform?**	**Why Did the Barrier Fail?**	**How Did the Barrier Affect the Accident?**
Safety Basis	Failed	The current Safety Basis document: • Did not take into account the known damaged fuel plates; • Inaccurately established a failure rate of Pu plate cladding to be extremely unlikely; • Failed to analyze the plausibility/probability/risk of cladding failure. • Did not assess the potential exposure to the workers within the facility	The failure of this barrier resulted in insufficient radiological controls being established for this activity. The Safety Basis gave the workers a false sense of security for their safety regarding potential for Pu fuel plate failures (cladding breach) **B1**

Hazard: Transuranic Material		**Target: Workers & Facility**	
What Were the Barriers?	**How Did Each Barrier Perform?**	**Why Did the Barrier Fail?**	**How Did the Barrier Affect the Accident?**
Fuel Plate Matrix (Fuel Form)	Failed	• Moisture and air infiltration led to oxidation and the formation of hydrides. • Fuel did not maintain solid form.	The failure of this barrier allowed for the formation of an easily dispersible particulate **B2**
Fuel Plate Cladding	Failed	Unknown	The Pu oxidation byproducts provided the source for this contamination and exposure accident. **B3**
Plastic and Tape Wrapping	Bypassed	Tape and plastic was intentionally removed and cut. Whether intended or not, the plastic appeared to have aided containment of material.	The bypass of this barrier allowed for the release of material. **B4**
Workroom Hood	Failed	Was not specifically designed or qualified for this work.	This barrier did not prevent the uncontrolled release of radioactivity. **B5**
Glovebox	Not Used	Was not used.	The use of this barrier could have prevented an uncontrolled release of radioactivity. **B6**

Hazard: Transuranic Material		**Target: Workers & Facility**	
What Were the Barriers?	**How Did Each Barrier Perform?**	**Why Did the Barrier Fail?**	**How Did the Barrier Affect the Accident?**
Pu Awareness Training	Failed	• The training is not performance based (no test). • There is no periodic requirement for reinforcement. • The training is not mandatory.	The failure of this barrier led to workers remaining in the Workroom while a smear was assessed, thus increasing their time of exposure. The training did not result in worker recognition of the hazards associated with loose and visible quantities of Pu material in the fume hood. **B7**
ALARA Review	Failed	The ALARA review: • Was developed with an inadequate institutional knowledge of facility hazards; • Did not result in the identification of the hazard; • Did not evaluate possible upset conditions.	This barrier did not result in the use of hazard controls that were appropriate for the work being performed. **B8**
PPE	Failed	Respiratory protection and anti-contamination clothing was not used.	As prescribed by the RWP, respiratory protection and anti-contamination clothing did not prevent intakes and contamination of personnel, respectively. **B9**

Hazard: Transuranic Material		Target: Workers & Facility	
What Were the Barriers?	**How Did Each Barrier Perform?**	**Why Did the Barrier Fail?**	**How Did the Barrier Affect the Accident?**
Stop Work Process	Failed	No worker or supervisor invoked it when warranted.	The failure of this barrier resulted in work continuing. **B10**
Supervision (SS and NFM)	Failed	Training and experience of the supervision did not lead them to thoroughly evaluate the abnormal condition or utilize technical resources before making the decision to proceed with work.	The failure of this barrier resulted in the decision to proceed with work that was hazardous and unevaluated. **B11**
Independent Safety Review Committee (ISRC) Chairman's White Paper	Failed	The White Paper did not result in follow-up on the issue of Pu fuel plate failure.	The failure of this barrier allowed work to continue under current conditions. **B12**
Senior MFC Management	Failed	Did not recognize the significance of the information provided by the ISRC Chairman's White Paper.	The failure of this barrier did not result in review of safety basis adequacy. **B13**

Appendix C: Change Analysis

Change is anything that disturbs the “balance” of a system from operating as planned. Change is often the source of deviations in system operations. Change can be planned, anticipated, and desired, or it can be unintentional and unwanted. Change analysis examines the planned or unplanned disturbances or deviations that caused the undesired results or outcomes related to the accident. This process analyzes the difference between what is normal (or “ideal”) and what actually occurred. The results of the change analysis are used to support the development of causal factors.

Table C-1: Change Analysis

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
The plastic & tape wrapped plate was cut in a hood	The plastic & tape wrapped was cut in a glovebox	The glovebox provides containment over confinement.	The glovebox would prevent the release to the Workroom and workers **C1**
A “time out” was taken. Work continued without identifying additional information prior to proceeding	The “time out” resulted in a “stop work” and subsequently a re-evaluation was conducted prior to continuing with additional controls to address the potential hazards	A more formal process was used to understand, assess and adjust hazard controls prior to continuing work	A more rigorous analysis would be conducted to address any additional hazards and required controls. **C2**
The worker and facility impacts resulting from a damaged fuel plate (Pu) were not accurately evaluated (re-evaluated) in the safety basis.	The safety basis included a correct evaluation of the impacts of a damaged fuel plate (Pu) on the facility and its operations.	Appropriate hazard controls were identified as a planned response to fuel plate failure.	This work activity would have been performed with a better understanding of the hazards involved. **C3**
Workers were not wearing respiratory protection and full anti-contamination clothing while performing work.	When performing work in the hood the workers would have been wearing anti-contamination clothing	Workers would be afforded increased protection from an uncontrolled release of radioactivity	Consequences of uncontrolled release are reduced **C4**

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
All workers had limited knowledge relative to Pu fuel plates history	A formal process assures continuity of knowledge and experience are maintained	Knowledge transfer occurred	Workers and Supervision have the knowledge, experience and respect of the hazards **C5**
There were no CAMs in place specific to the work	CAMs are used to monitor the work area and breathing zone of the workers	CAMs could have alarmed sooner than the Vault CAM	CAMs appropriately positioned would have reduced the time to alarm, reducing personnel exposure. **C6**
Thirteen workers in the room at the time of the release	The number of personnel involved in the work activity are minimized	Fewer people are present and exposed to potential hazards	Consequences of contamination were reduced **C7**
Workers did not understand the consequences of Pu contamination	Workers are aware and knowledgeable of the hazards/consequences of Pu contamination. (Magnitude of release)	Workers would have a more questioning attitude toward the approach to work.	There would have been a higher probability of a "stop work" when encountering an abnormal condition. **C8**
Change of Contractor organizations and personnel caused a loss of knowledge/use of records that could indicate the conditions associated with the fuel plates.	The change in contracting organizations ensures a consistent and continuous level of knowledge concerning operational history of the fuel plates.	Changes in contracting organization (transition) resulted in some lost information sources about the condition of fuel plates.	Identifying the conditions of the fuel plates in the marked clamshells could have prevented opening the clamshell and selecting a different (good condition) fuel plate. Lost opportunity to stop. **C9**

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
Information concerning the fuel plates was kept by several methods, not all having the capability to capture the physical conditions	One method was used to capture the information to handle/store fuel safely	Physical condition of the fuel plates would be readily available from a single source when abnormal conditions arise	Accurate information would be available to the workers/supervision to make informed decisions when abnormal conditions are observed. **C10**
The work was performed with the Vault door open	Work was performed in a tested configuration (i.e., Vault door closed)	The air flow in the room is understood based upon known air flow	The work is performed within controls **C11**

Appendix D: Human Performance Analysis

In human performance improvement (HPI), error precursors are unfavorable conditions that increase the probability for error during a specific action and create what are known as error-likely situations. An error-likely situation typically exists when the demands of the task exceed the capabilities of the individual or when work conditions exceed the limitations of human nature.

The Board analyzed error precursors by conducting interviews and reviewing records, logs and other documentation, as discussed in the analyses of this report. The Board determined that weakness in several areas of Human Performance contributed to establishing causal factors that led to this accident. The results of that analysis are presented below in Table D-1.

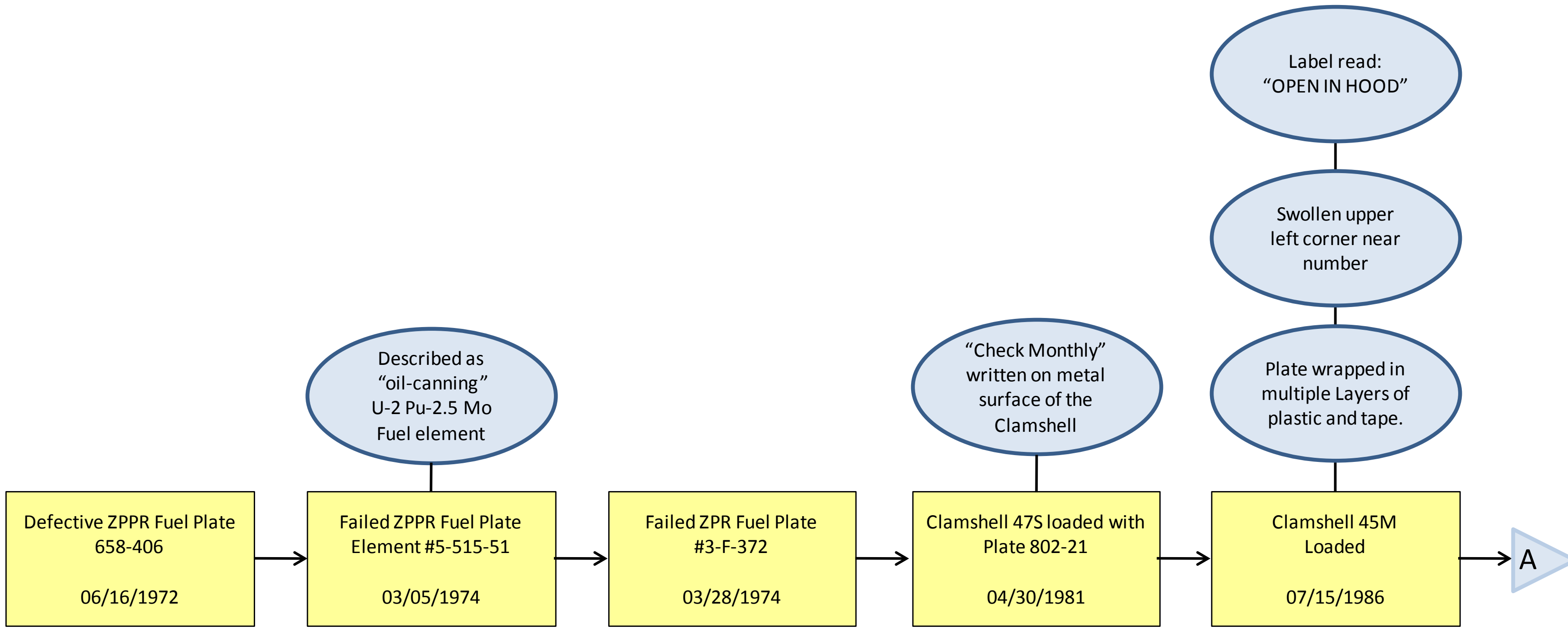
Table D-1. HPI Accident Precursors

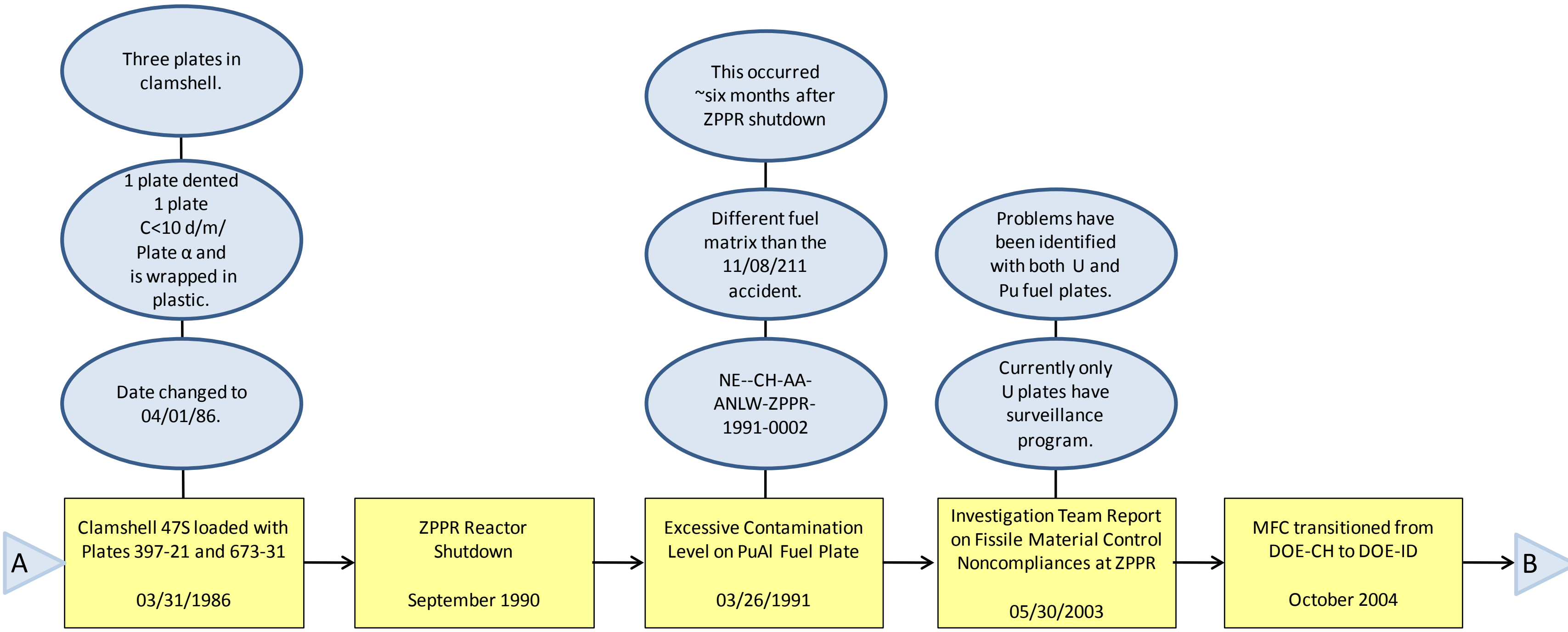
TASK DEMANDS	INDIVIDUAL CAPABILITIES
Repetitive action, monotonous See Section 2.4.2.1 Pu Fuel Plate Source Term	**Lack of knowledge (mental model)** See Sections 2.4.2 Safety Basis and 2.4.3.5 Training for Work
Irrecoverable acts See Section 2.4.3.4 Execution of Work	**Imprecise communication habits** See Section 2.4.3.4 Execution of Work
WORK ENVIRONMENT	HUMAN NATURE
Changes/Departures from routine See Section 2.4.3.4 Execution of Work	**Assumptions (inaccurate mental picture)** See Section 2.4.2 Safety Basis
	Complacency/Overconfidence See Section 2.4.2 Safety Basis
	Inaccurate risk perception See Sections 2.4.2 Safety Basis and 2.4.3.5 Training for Work

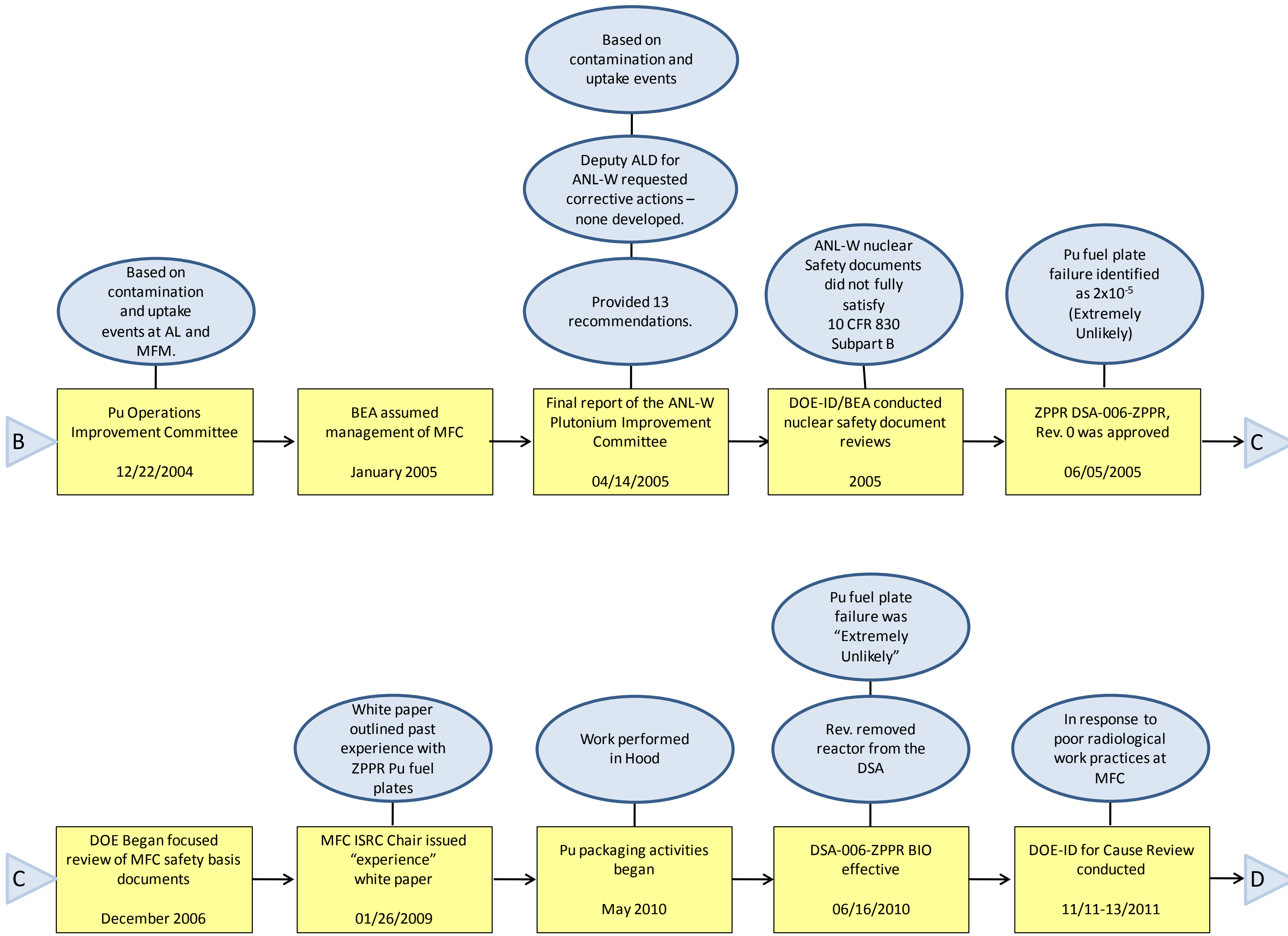
Appendix E: Events and Causal Factor Analysis

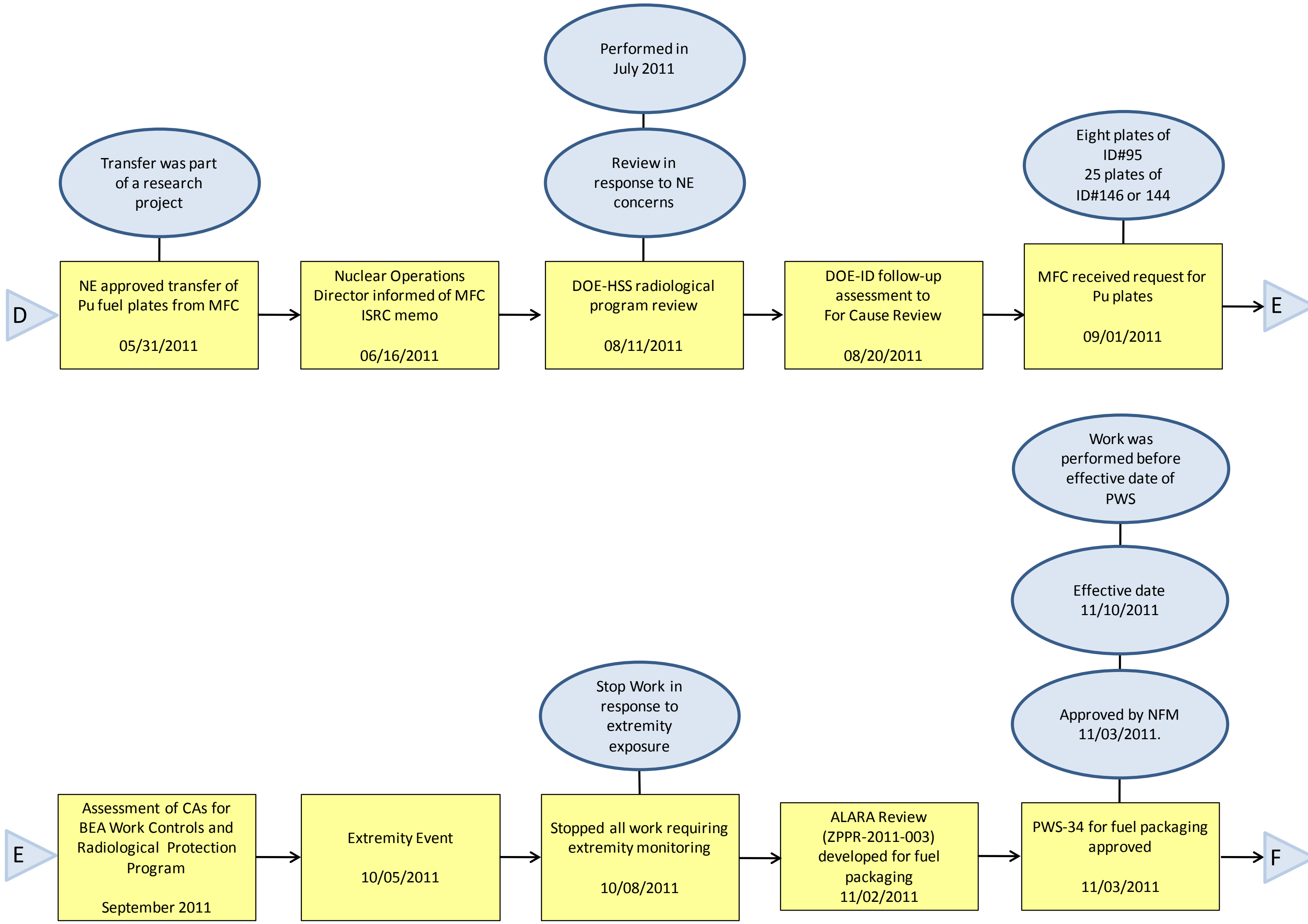
An events and causal factors analysis was performed in accordance with the DOE Workbook *Conducting Accident Investigations*. The events and causal factors analysis requires deductive reasoning to determine those events and/or conditions that contributed to the accident. Causal factors are the events or conditions that produced or contributed to the accident, and they consist of direct, contributing, and root causes. The direct cause is the immediate event(s) or condition(s) that caused the accident. The contributing causes are the events or conditions that, collectively with the other causes, increased the likelihood of the accident, but which did not solely cause the accident. Root causes are the events or conditions that, if corrected, would prevent recurrence of this and similar accidents. The causal factors are identified in Table E-1.

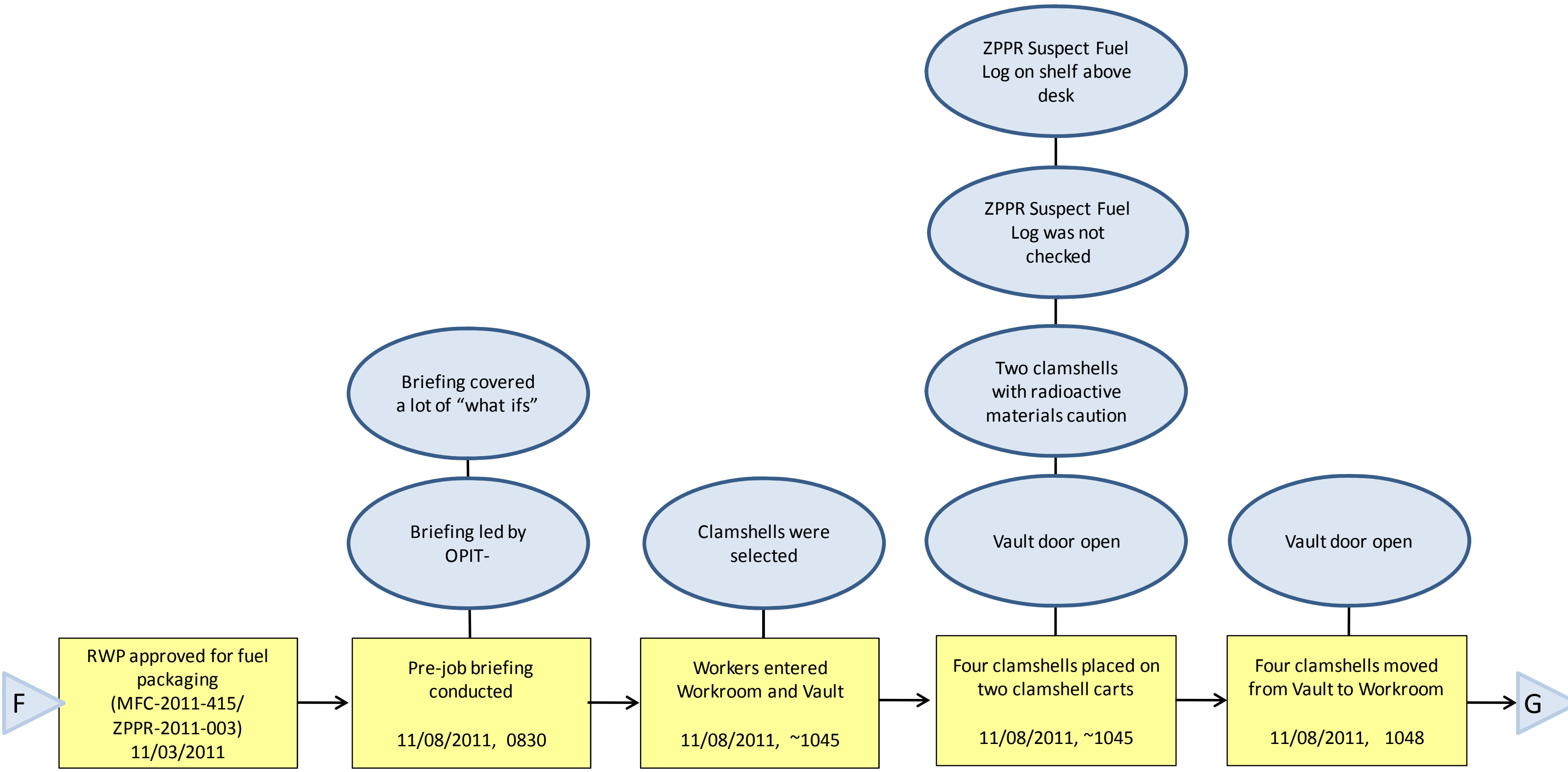
Table E-1: Events and Causal Factor Chart

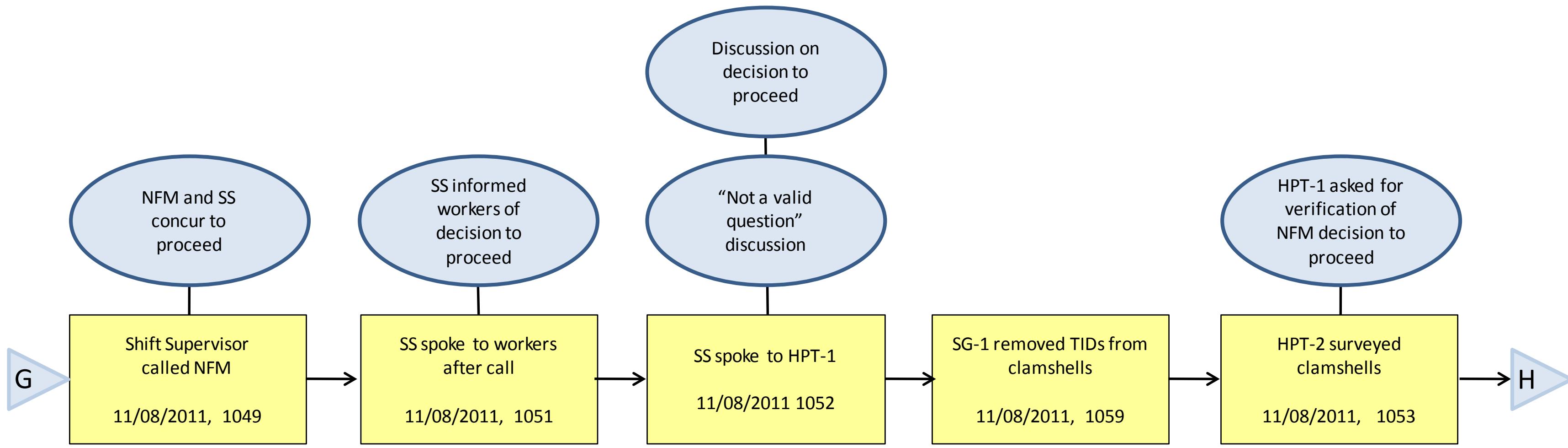


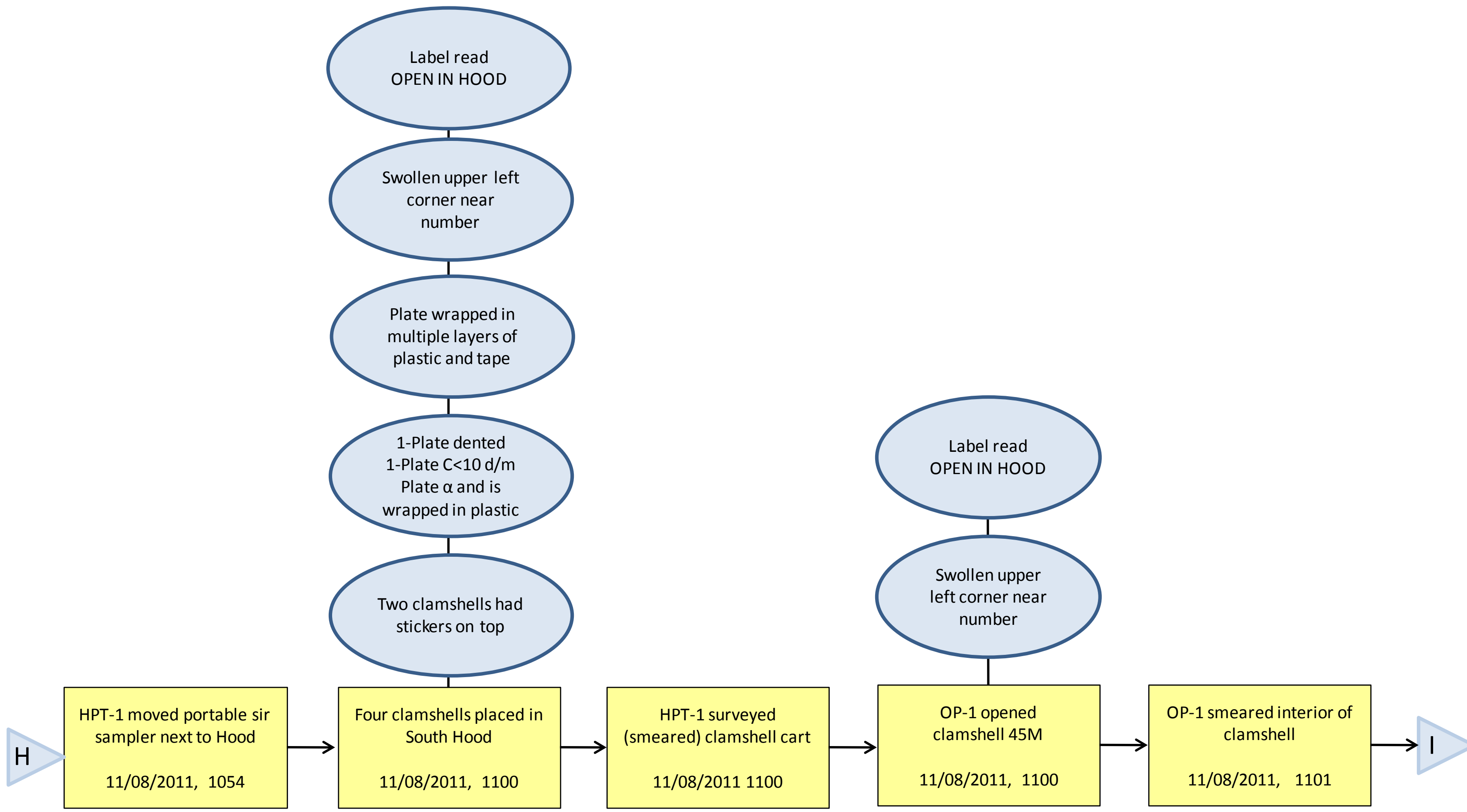

Three plates in clamshell.
1 plate dented
1 plate
C<10 d/m/
Plate α and
is wrapped in plastic.
Date changed to 04/01/86.
A
Clamshell 47S loaded with Plates 397-21 and 673-31
03/31/1986
ZPPR Reactor Shutdown
September 1990
This occurred ~six months after ZPPR shutdown
Different fuel matrix than the 11/08/211 accident.
NE--CH-AA-ANLW-ZPPR-1991-0002
Excessive Contamination Level on PuAl Fuel Plate
03/26/1991
Problems have been identified with both U and Pu fuel plates.
Currently only U plates have surveillance program.
Investigation Team Report on Fissile Material Control Noncompliances at ZPPR
05/30/2003
MFC transitioned from DOE-CH to DOE-ID
October 2004
B

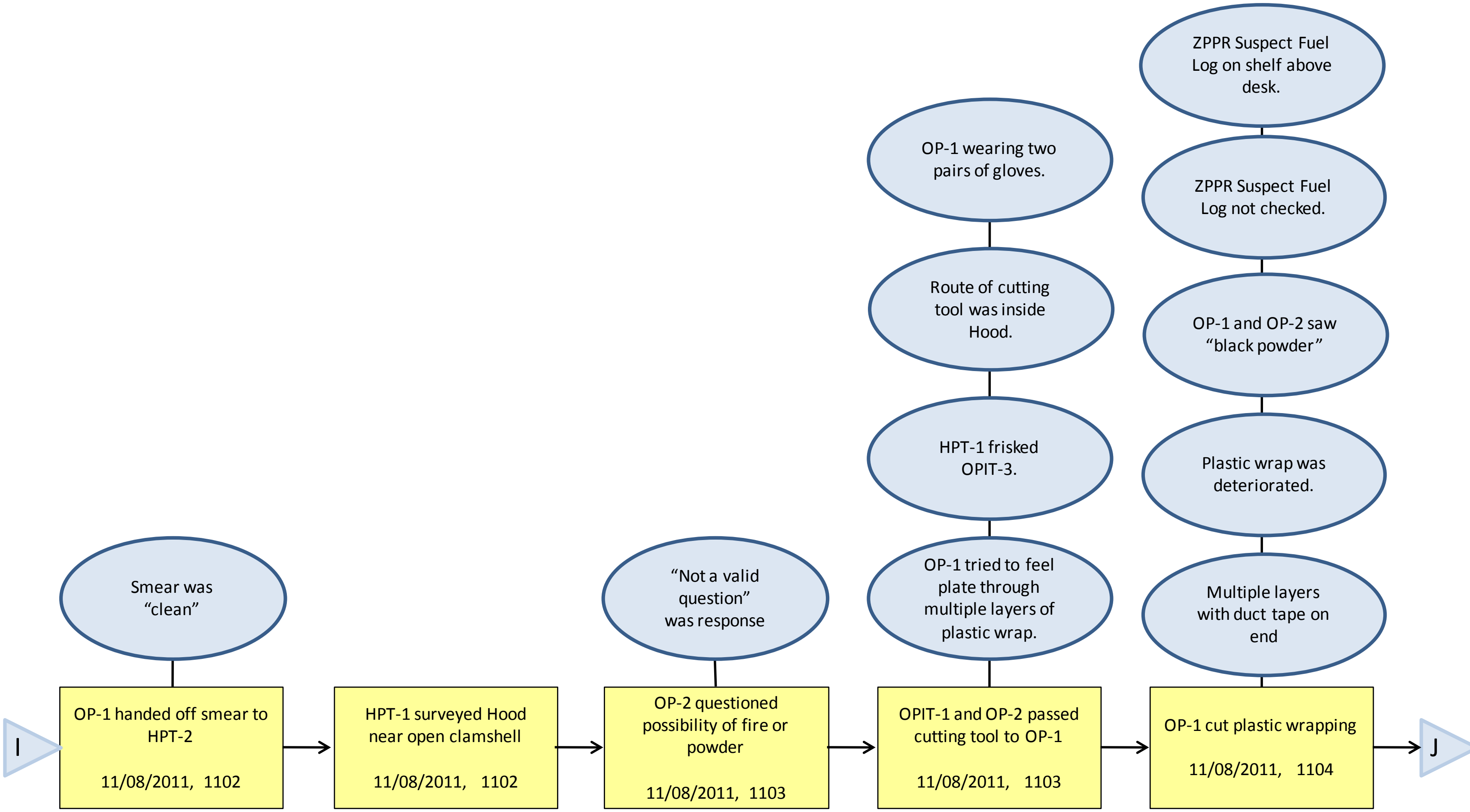

Based on contamination and uptake events
Deputy ALD for ANL-W requested corrective actions – none developed.
Based on contamination and uptake events at AL and MFM.
Provided 13 recommendations.
ANL-W nuclear Safety documents did not fully satisfy 10 CFR 830 Subpart B
Pu fuel plate failure identified as 2x10-5 (Extremely Unlikely)
B
Pu Operations Improvement Committee
12/22/2004
BEA assumed management of MFC
January 2005
Final report of the ANL-W Plutonium Improvement Committee
04/14/2005
DOE-ID/BEA conducted nuclear safety document reviews
2005
ZPPR DSA-006-ZPPR, Rev. 0 was approved
06/05/2005
C
Pu fuel plate failure was "Extremely Unlikely"
White paper outlined past experience with ZPPR Pu fuel plates
Work performed in Hood
Rev. removed reactor from the DSA
In response to poor radiological work practices at MFC
C
DOE Began focused review of MFC safety basis documents
December 2006
MFC ISRC Chair issued "experience" white paper
01/26/2009
Pu packaging activities began
May 2010
DSA-006-ZPPR BIO effective
06/16/2010
DOE-ID for Cause Review conducted
11/11-13/2011
D

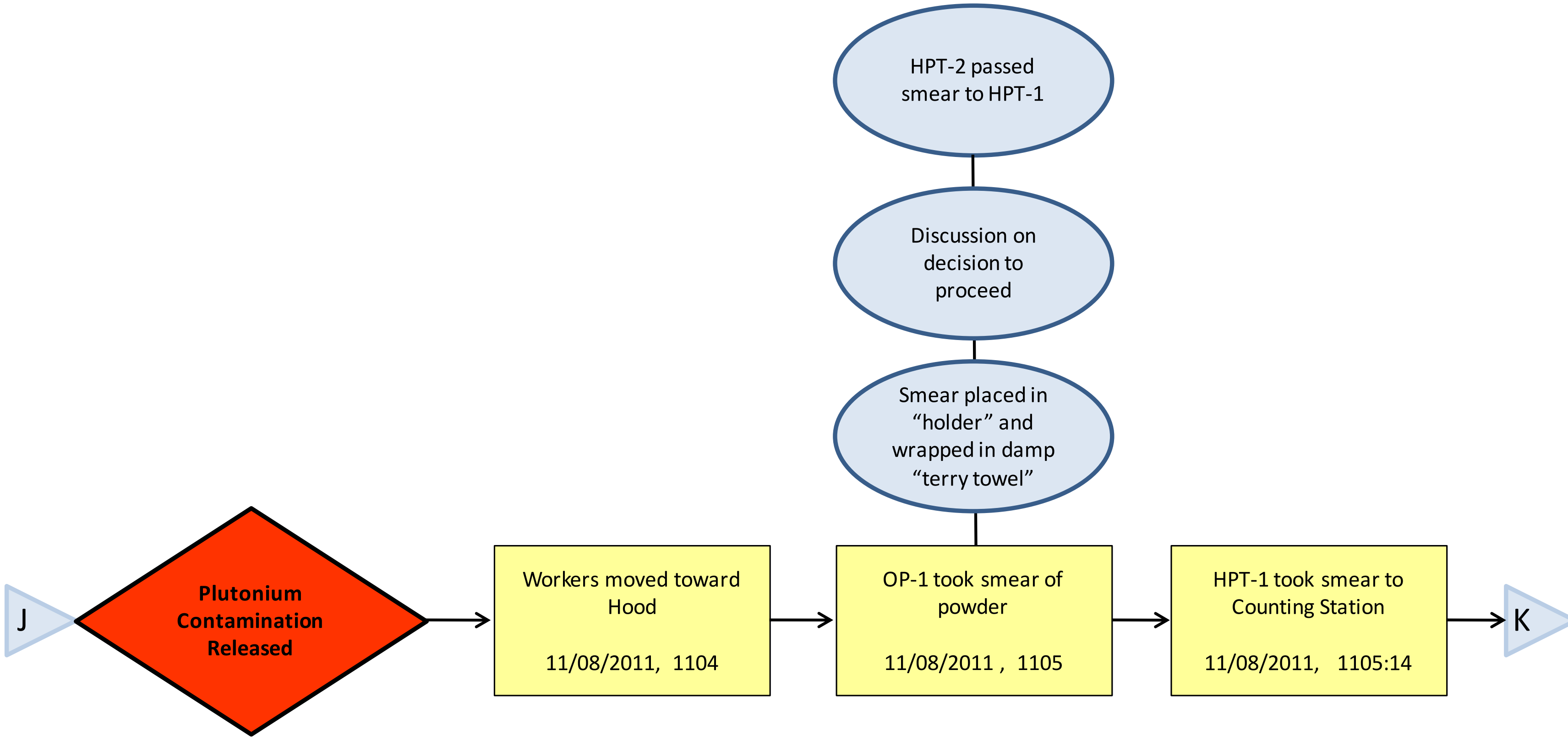

Transfer was part of a research project
Performed in July 2011
Review in response to NE concerns
Eight plates of ID#95 25 plates of ID#146 or 144
D
NE approved transfer of Pu fuel plates from MFC 05/31/2011
Nuclear Operations Director informed of MFC ISRC memo 06/16/2011
DOE-HSS radiological program review 08/11/2011
DOE-ID follow-up assessment to For Cause Review 08/20/2011
MFC received request for Pu plates 09/01/2011
E
Work was performed before effective date of PWS
Effective date 11/10/2011
Stop Work in response to extremity exposure
Approved by NFM 11/03/2011.
E
Assessment of CAs for BEA Work Controls and Radiological Protection Program September 2011
Extremity Event 10/05/2011
Stopped all work requiring extremity monitoring 10/08/2011
ALARA Review (ZPPR-2011-003) developed for fuel packaging 11/02/2011
PWS-34 for fuel packaging approved 11/03/2011
F

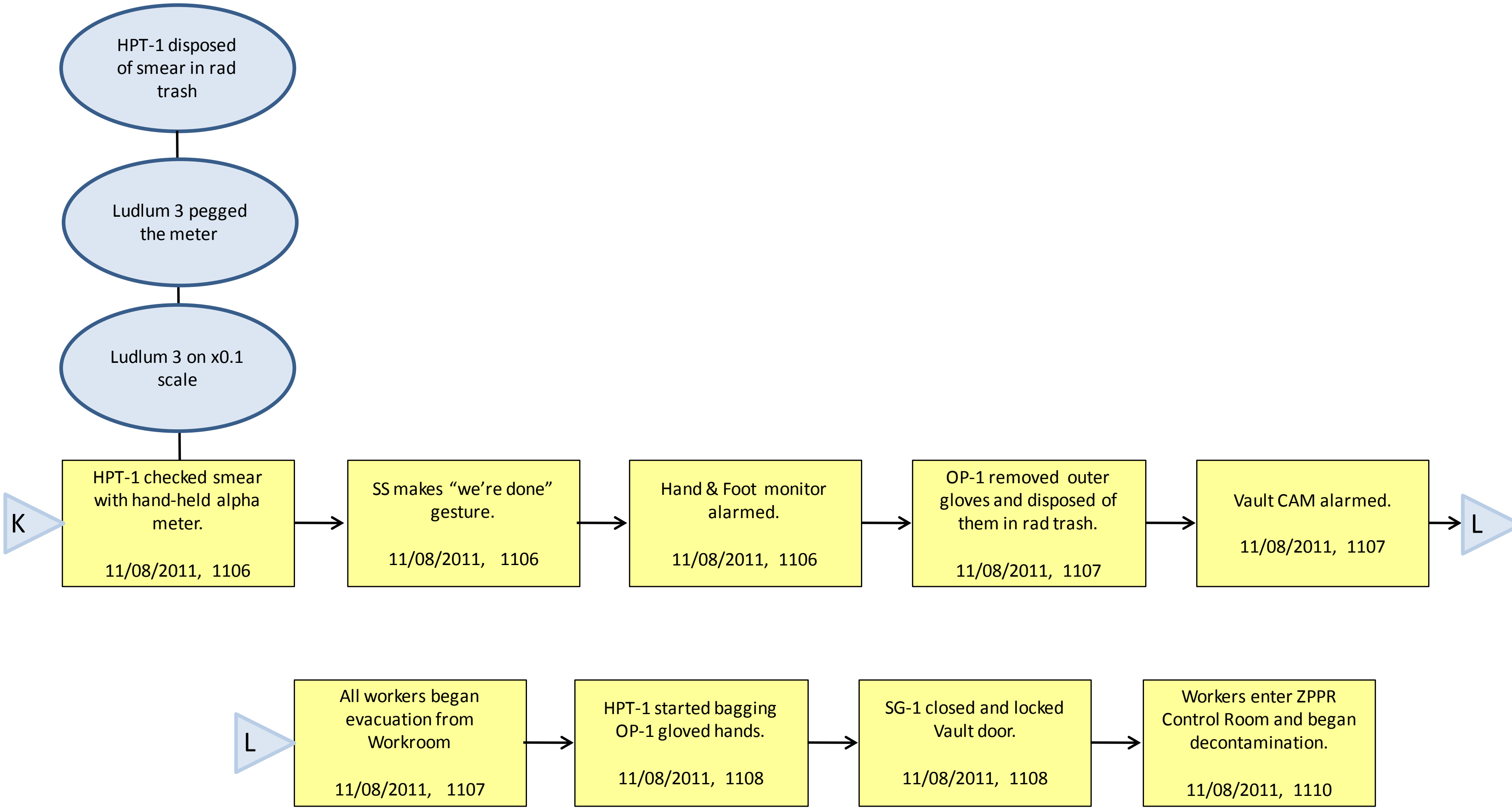

F
RWP approved for fuel packaging (MFC-2011-415/ ZPPR-2011-003) 11/03/2011
Briefing covered a lot of "what ifs"
Briefing led by OPIT-
Pre-job briefing conducted
11/08/2011, 0830
Clamshells were selected
Workers entered Workroom and Vault
11/08/2011, ~1045
ZPPR Suspect Fuel Log on shelf above desk
ZPPR Suspect Fuel Log was not checked
Two clamshells with radioactive materials caution
Vault door open
Four clamshells placed on two clamshell carts
11/08/2011, ~1045
Vault door open
Four clamshells moved from Vault to Workroom
11/08/2011, 1048
G


G
Shift Supervisor called NFM
11/08/2011, 1049
NFM and SS concur to proceed
SS spoke to workers after call
11/08/2011, 1051
SS informed workers of decision to proceed
SS spoke to HPT-1
11/08/2011 1052
"Not a valid question" discussion
Discussion on decision to proceed
SG-1 removed TIDs from clamshells
11/08/2011, 1059
HPT-2 surveyed clamshells
11/08/2011, 1053
HPT-1 asked for verification of NFM decision to proceed
H


Label read
OPEN IN HOOD
Swollen upper left corner near number
Plate wrapped in multiple layers of plastic and tape
1-Plate dented
1-Plate C<10 d/m
Plate α and is wrapped in plastic
Two clamshells had stickers on top
Label read
OPEN IN HOOD
Swollen upper left corner near number
H
HPT-1 moved portable sir sampler next to Hood
11/08/2011, 1054
Four clamshells placed in South Hood
11/08/2011, 1100
HPT-1 surveyed (smeared) clamshell cart
11/08/2011 1100
OP-1 opened clamshell 45M
11/08/2011, 1100
OP-1 smeared interior of clamshell
11/08/2011, 1101
I


I
OP-1 handed off smear to HPT-2
11/08/2011, 1102
Smear was "clean"
HPT-1 surveyed Hood near open clamshell
11/08/2011, 1102
OP-2 questioned possibility of fire or powder
11/08/2011, 1103
"Not a valid question" was response
OPIT-1 and OP-2 passed cutting tool to OP-1
11/08/2011, 1103
OP-1 tried to feel plate through multiple layers of plastic wrap.
HPT-1 frisked OPIT-3.
Route of cutting tool was inside Hood.
OP-1 wearing two pairs of gloves.
OP-1 cut plastic wrapping
11/08/2011, 1104
Multiple layers with duct tape on end
Plastic wrap was deteriorated.
OP-1 and OP-2 saw "black powder"
ZPPR Suspect Fuel Log not checked.
ZPPR Suspect Fuel Log on shelf above desk.
J


HPT-2 passed smear to HPT-1
Discussion on decision to proceed
Smear placed in "holder" and wrapped in damp "terry towel"
J
Plutonium Contamination Released
Workers moved toward Hood
11/08/2011, 1104
OP-1 took smear of powder
11/08/2011 , 1105
HPT-1 took smear to Counting Station
11/08/2011, 1105:14
K


HPT-1 disposed of smear in rad trash
Ludlum 3 pegged the meter
Ludlum 3 on x0.1 scale
K
HPT-1 checked smear with hand-held alpha meter. 11/08/2011, 1106
SS makes "we're done" gesture. 11/08/2011, 1106
Hand & Foot monitor alarmed. 11/08/2011, 1106
OP-1 removed outer gloves and disposed of them in rad trash. 11/08/2011, 1107
Vault CAM alarmed. 11/08/2011, 1107
L
L
All workers began evacuation from Workroom 11/08/2011, 1107
HPT-1 started bagging OP-1 gloved hands. 11/08/2011, 1108
SG-1 closed and locked Vault door. 11/08/2011, 1108
Workers enter ZPPR Control Room and began decontamination. 11/08/2011, 1110

Appendix F: Chronology of ZPPR Safety Basis

Table F-1: Chronology of ZPPR Safety Basis

Date	Document	Comments
June 1972	ANL-7471, Final Safety Analysis Report [FSAR] on the Zero Power Plutonium Reactor (ZPPR) Facility	Addenda 1 – 20 with the latest in 1989
February 10, 1993	Approval of Revised Technical Specifications for the Zero Power Physics Reactor (ZPPR).	Removed reactor specific technical surveillances Fuel handling shall not be permitted in the Workroom unless: 1) The Workroom alpha monitor is operable and set to annunciate at 40 RCG-hr [1 RCG = 2 x 10-12 uCi/ml soluble ^{239}Pu], 2) The Workroom gamma monitor is operable…, 3) The gamma monitor on the mound area exhaust system is operable…, 4) The stack gamma monitor is operable and set to trip…, 5) The alpha monitors upstream and downstream of the mound exhaust filters are operable and set to trip…,
April 4, 2004	Technical Specifications Revision 3 approved	
April 7, 2003	10 CFR 830 ZPPR safety basis (DSA-006-ZPPR) submitted to DOE for review and approval	
January 7, 2005	Department of Energy Idaho Operations Office (NEID) Vulnerability Assessment	ANL-W is not in full compliance with Subpart of 10 CFR 830. Represents a significant vulnerability to DOE
January 14, 2005	BEA Transmittal of the INL Transition Report on Nuclear Facility Bases memo	Safety basis for ZPPR was not 10 CFR 830 compliant and no SER was issued. Degradation problem with some stored plutonium materials as discovered during the plutonium handling required for the 2003 Pu Vulnerability Action Plan

Date	Document	Comments
January 20, 2005	DOE approved Authorization Agreements for the MFC	
January 27, 2005	DOE issued a SER approving DSA-006-ZPPR	Safety basis as documented was acceptable based upon the condition of approvals listed below: 1) Deficiencies identified in the Department of Energy Idaho Operations Office (NEID) Vulnerability Assessment OS-QSD-05-005) shall be addressed in a formal plan with schedule and milestones by May 2, 2005. (COA 1) 2) Perform unmitigated calculations without taking credit for leak path factors so that it is apparent that structures along the leak path are not required to meet accident guidelines in the next annual update. (COA 3.3a) 3) A discussion of environmental protection shall be added per DOE-STD-3009 in the next annual update. (COA 3.3b) 4) A discussion on the qualitative evaluation of worker accident consequences for the facility worker as well as a discussion of major features protecting the workers from the hazards of facility operation shall be added per DOE-STD-3009 in the next annual update. (COA 3.3c) 5) In the next annual update, ANL-W should identify assumptions requiring TSR coverage in Chapter 4 of the DSA per DOE-STD-3009. These assumptions would be the limiting inventories of radionuclides and hazardous materials used in the accident analysis (material at risk). (COA 4.3)
February 25, 2005	DSA-006-ZPPR implemented	
April 26, 2005	DOE approved Equivalent Position/Organization Titles and Document Identifier Changes for Materials and Fuels Complex Nuclear Facilities	

Date	Document	Comments
June 23, 2005	DOE Safety Evaluation Report Addendum Material and Fuels Complex Zero Power Physics Reactor	(For organizational changes, no technical changes)
July 28, 2005	NS-18308, Revision 0, MFC Work Plan for Safety Basis Upgrade	ZPPR – Reactor Cell and Workroom/Vault ranked 2nd in priority,SAR-412 and TSR-412 submittal scheduled for October 2007
June 20, 2006	DOE issued a SER approving DSA-006-ZPPR Revision 2	Three new controls were directed by DOE as the result of a USQ involving a seismic event that results in a fire in the Vault. (Co-located worker was reduced to 100 meters) Added the unmitigated workers dose to Table 3-11 so that it is readily apparent that structures along the leak path are not required to meet evaluation guidelines. This also closes out condition of approval (COA) 3.3a from the safety evaluation report noted as record #4. Added a discussion of environmental protection per DOE-STD-3009. This also closes out COA 3.3b from the safety evaluation report noted as record #4. Added a qualitative evaluation of facility worker accident consequences and the major features protecting workers. This also closes out COA 3.3c from the safety evaluation report noted as record #4. Inserted within Chapter 4, "Safety SSCs and passive design features" on the use of a TSR administrative control to protect assumptions relative to inventory material-at-risk. This closes out COA 4.3 from the safety evaluation report noted as record #4.
April 20, 2007	DOE approved SAR-400 and TSR-400 Revision 0	No direct affect on
May 22, 2007	DOE concurred with a Contractor recommendation to revise the prioritization of MFC DSA upgrades	ZPPR listed as sixth in priority.

Date	Document	Comments
July 31, 2007	DOE issued a SER approving DSA-006-ZPPR Revision 3	
September 17, 2007	Approval of the Evaluation of the Safety of the Situation and Justification for Continued Operations from the Nuclear Safety Management Potentially Inadequate Safety Analysis at the Material and Fuels Complex	The PISA identified that: 1) MFC safety basis documents contain both "mitigated" and "unmitigated" accident analysis, 2) the in-facility and co-located dose consequences are established at the MFC parking lot, and 3) in certain cases the facility hazard categorization was not in accordance with DOE-STD-1027-92 and the identification of material at risk accounted for only a limited inventory. The USQ resolution plan consisted of performing specific tasks necessary to upgrade existing MFC safety bases to bring these documents into compliance with the nuclear safety management rule 10 CFR 830, Subpart B, in a manner that is consistent with DOE-ID's expectations per supplemental guidance, record #7, and in a time frame consistent with DOE expectations through approval of this plan and future INL submittals. The justification for continued operations (JCO) and final operability determination found that facility operations are justified to continue operations given the strong framework of integrated safety management (ISM), the implementation of site wide safety management programs and continued use of the following interim TSR controls: MFC/Sitewide-1 The Idaho National Laboratory (INL) will operate MFC Hazard Category 2 and 3 nuclear facilities/activities with their existing safety basis. MFC/Sitewide-2 The INL will enter the PISA process for deficiencies not described in the DOE-ID vulnerability assessment and BEA Transition Review. MFC/Sitewide-3 The INL will maintain the existing safety basis, apart from the deficiencies identified in the DOE-ID vulnerability assessment and BEA Transition Review.

Date	Document	Comments
		MFC/Sitewide-4 If a condition/situation is identified during the MFC DSA upgrade process that warrants entering the PISA/USQ process so that compensatory controls can be developed and put in place for worker/public protection, then immediate action appropriate to the circumstance will be taken. **DOE COA:** INL shall conduct a review of ongoing and planned operations in MFC nuclear facilities identified in Table 1 and develop proposed additional facility specific TSR controls, as necessary, to enhance the safety of these operations in the interim pending upgrade of the associated facility documented safety analysis. Table 1 specified a deliverable date of November 16, 2007 for ZPPR. The INL shall provide the documented initial facility hazards evaluation developed to support the upgrade of each MFC nuclear facility DSA to DOE-ID for inclusion and use. These evaluations will identify the systems, structures, and components (SSCs) anticipated for selection as safety class or safety significant SSCs in the upgraded document. These evaluations shall be provided no later than the deliverable date provided in Table 2. The deliverable date for ZPPR was within three months after commencing ZPPR safety basis upgrade per NS-18308, current revision and no later than November 2009. Upon INL completion of the documented initial facility hazards evaluation discussed in item 2 above, an assessment team whose membership will include representation from the DOE Central Technical Authority, a cognizant DOE-ID safety system oversight engineer, and an INL system engineer shall conduct a joint system review of the selected facility DSAs.
November 11, 2007	NS-18308, Revision 2	ZPPR safety basis ranked as 9th priority
March 31, 2008	DOE approval of Revision 3 to the ESS and JCO of MFC nuclear facilities	

Date	Document	Comments
April 7, 2008	DOE issued a SER approving DSA-006-ZPPR Revision 4	DOE Directed Changes To provide additional clarity and consistency on one of the new TSR administrative controls, DSA-006-ZPPR, chapter 5A, ZPPR Administrative Control, AC.5 .16 Fuel Storage Component Inspection Program shall be revised to read as follows: AC.5.16 Fuel Storage Component Inspection Program A written facility-specific ZPPR fuel storage component inspection program shall be implemented to provide assurance that the important to safety (ITS) passive design features remain capable of performing their intending functions. This inspection program shall be comprised of the pin and plate clamshells, pin canisters, and Pu plate and pin jackets. Bases: The fuel storage component inspection program establishes an inspection program that ensures the ITS passive design features continue to fulfill their intended functions as defined in section 4.3 through 4.5 of DSA-006-ZPPR. This inspection will ensure the relied upon design features will continue to provide their mitigative safety function while in passive Vault storage within ZPPR.
December 18, 2008	DOE issued a SER approving DSA-006-ZPPR Revision 5 (high enriched uranium plate surveillance)	
July 21, 2009	DOE issued a SER approving DSA-006-ZPPR Revision 6	
March 29, 2010	DOE issued a SER approving DSA-006-ZPPR Revision 7	
May 19, 2010	NS-18308 Revision 4	

Date	Document	Comments
June 16, 2010	Documented Safety Analysis Materials and Fuels Complex ZPPR Documented Safety Analysis, DSA-006-ZPPR, Revision ID: 7, Effective	Establishes material at risk value for Pu fuel plates. Damage ratio of 0.25 is applied when analyzing events involving Pu plates and pins which are clad in stainless-steel jackets.
July 18, 2011	BEA submittal of DSA-006-ZPPR Revision 8	
	BEA retracted submittal of DSA-006-ZPPR Revision 8	
September 27, 2011	BEA submittal of BIO and TSR for ZPPR (SAR-412 and TSR-412 Revision 0)	
October 3, 2011	DOE approved NS-18308	Provides ESS and JCO for MFC facilities. The ESS became an addendum to each existing MFC nuclear facility/activity safety basis and included TSR controls AC ESS.MFC/Sitewide-1, ESS.MFC/Sitewide-2, ESS.MFC/Sitewide-3, and ESS.MFC/Sitewide-4 remained in effect.
October 27, 2011	BEA re-submittal of Revision 8 to DSA-006-ZPPR	
November 1, 2011	NS-18308, Revision 5	