22 January 2009

MEMORANDUM FOR Patrick Gallagher
Deputy Director, NIST

Rich Kayser
Chief Scientist, NIST

From: Lisa Karam
Chairman, NIST Ionizing Radiation Safety Committee

Subject: Booz Allen Hamilton's "Root Cause Analysis Report of Plutonium Spill at Boulder Laboratory"

Attached is the final root cause analysis report regarding the last June's plutonium spill at the NIST facilities in Boulder, Colorado ("Root Cause Analysis Report of Plutonium Spill at Boulder Laboratory"), as prepared by Booz Allen Hamilton (BAH). It has been reviewed and accepted by the Ionizing Radiation Safety Committee (IRSC), although the IRSC still has a few comments regarding this Final Report.

BAH states in Section E that the "recommendations included in this report are provided for NIST consideration, and ***were not required*** in the scope of the contract with Booz Allen Hamilton;" BAH, considering that they did not review the whole of the NIST safety program, should have limited recommendations to those pertaining to only the areas of review. Also, in Appendix B, many of the "gaps" are (generally) indicated for "corrective action" issues, which, as far as we recall, were not really part of the scope of the contract.

In Section 2.1.1, BAH mentions HPIs (Health Physics Instructions) when they seem to be referring to HSIs (Health and Safety Instructions) in the statement, "Although NIST has developed numerous hazardous material handling procedures (primarily through Health Physics Instructions (HPIs)) including the handling and use of radioactive material,…" since hazards extend beyond the HP issue. It seems that the statement should probably read, "Although NIST has developed numerous hazardous material handling procedures in Health and Safety Instructions (HSIs), including the handling and use of radioactive material through Health Physics Instructions (HPIs),…" Another point brought up by the IRSC refers to a statement in 2.1.5 ("The individual researcher also bears culpability for the accident"); although there had been a failure of the individual to understand the hazards and to respond/react appropriately after the vial broke, as is mentioned throughout the report, the individual was not trained to respond adequately and was unsupervised. One or the other might have prevented or lessened the severity of the situation.

Thank you for your consideration of this report, and I look forward to discussing the findings at greater length with you in the near future. I will be working with Wade Richards to select possible dates for a briefing.

Cc: IRSC membership

ROOT CAUSE ANALYSIS REPORT OF PLUTONIUM SPILL AT BOULDER LABORATORY

Submitted by:

Booz | Allen | Hamilton

delivering results that endure

Submitted to:
NIST, Gaithersburg, Maryland

January 07, 2009

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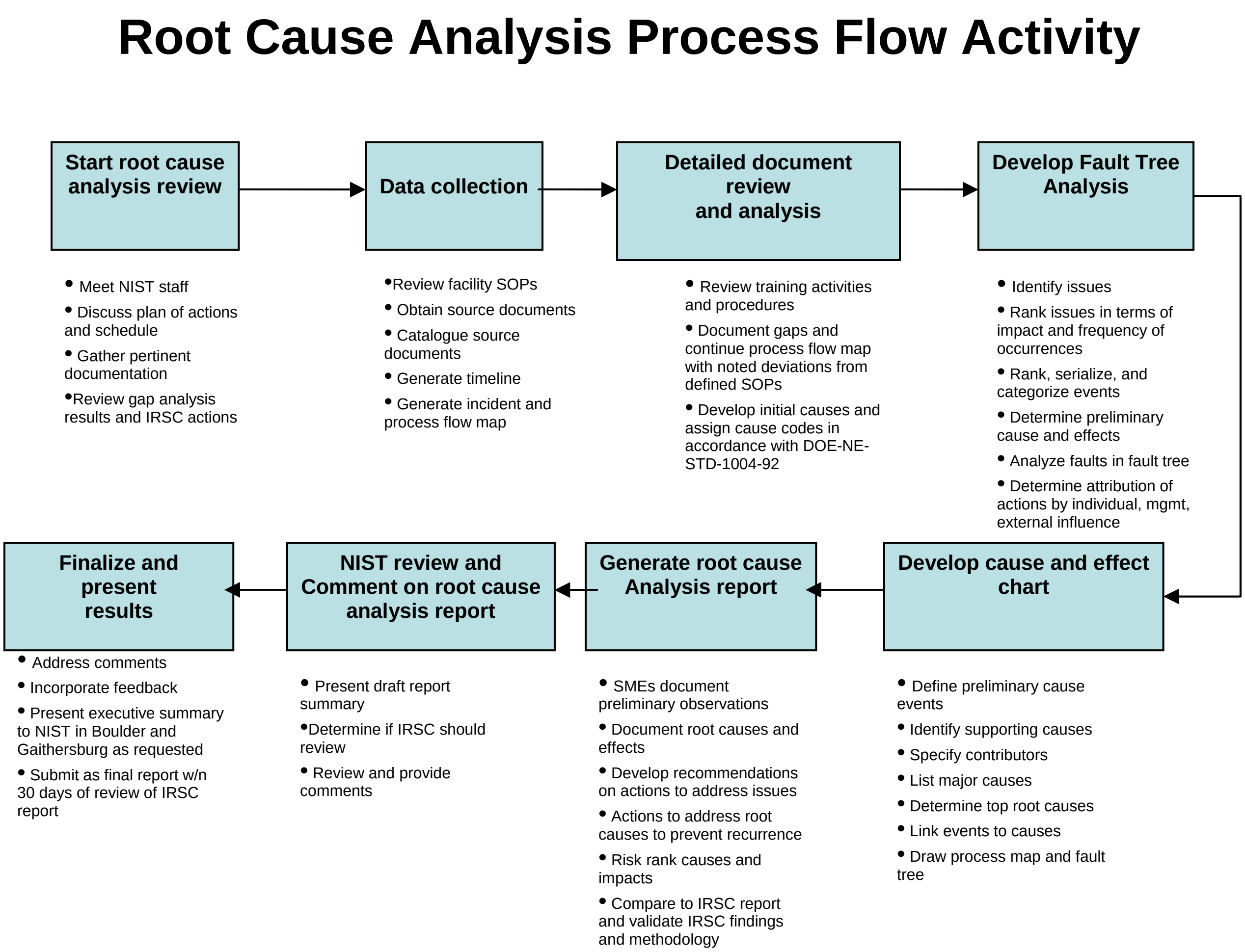
I. INTRODUCTION

Booz Allen Hamilton was contracted to conduct a root cause analysis of the plutonium spill at NIST's facilities in Boulder, Colorado. Booz Allen Hamilton presented the approach for conducting the root cause analysis to NIST management, and received concurrence. The process used was as follows:



The purpose of conducting an independent root cause analysis was to validate the methodology of the Ionizing Radiation Safety Review Committee (IRSC) utilized in their analysis of the plutonium spill, as well as validate conclusions specified in the IRSC report. This root cause analysis also addressed the recommendation in the IRSC report to conduct an independent root cause analysis.

The objectives of the root cause analysis were:

1. To validate the findings identified in the IRSC initial report of Plutonium contamination at NIST Boulder
2. To ensure that the root cause analysis was conducted in accordance with the DOE standard DOE-NE-STD-1004-92

3. To provide an independent, detailed, formal root cause analysis based on the DOE standard using cause and effect methodology

The root cause analysis was conducted over a 90 day period, and followed prescribed formal processes. A gap analysis using a checklist in conformance with the DOE Root Cause Standard was used, and the gaps in approach or documents were recorded. During the course of the analysis, the Booz Allen Team reviewed **source documents** (see **Attachment A** for a listing of the source documents) to address the gaps. The results of this effort are identified in an updated **Gap Analysis Checklist** (see **Attachment B**).

The root cause analysis was conducted by the following Booz Allen Hamilton project team members:

I. Jake Lefman- Project Manager
Nicholas Bahr- Root Cause Analysis Subject Matter Expert
Frank C. Hood- Environment, Safety, and Health Subject Matter Expert
Chris Juchau- Nuclear Analyst

The Booz Allen Hamilton team was selected to conduct this root cause analysis based on their collective experience in conducting formal root cause investigations as well as accident investigations.

Jake Lefman

Mr. Jake Lefman, the Project Manager, has over 25 years of solid project management experience and also has led and conducted numerous root cause and accident investigations. Mr. Lefman has more than 30 years of program management, client management, and assessment experience in the nuclear energy sector. He managed activities at nuclear power plants, managed the operation of a nuclear research reactor, supported the Nuclear Regulatory Commission (NRC) in nuclear licensing and support activities, and conducted assessments and reviews at several operating nuclear facilities. He was a participant in an independent investigation team to evaluate and report the issues involved regarding alleged falsifications of records at a National Laboratory. This independent team investigated the issues, created a timeline, developed cause and effects analyses, and recommended actions to address the issues and actions to preclude recurrence. He also participated in the investigation and root cause analysis of a major oil pipeline rupture and spill in a sensitive habitat environment for an oil and gas company under Congressional scrutiny.

Mr. Lefman has been providing technical support to the Department of Energy (DOE) in many areas, including the Office of Civilian Radioactive Waste Management, Defense Programs, Office of Environmental Management, and Office of Environment, Safety, and Health. He has managed key activities in nuclear technology, information technology and outsourcing, oil and gas exploration, call center management, environmental activities, infrastructure development, and command, control, communications, computers, and intelligence (C4I) security systems.

Mr. Lefman started his nuclear career working for a major Architect Engineer Constructor as an Engineer performing oversight of construction of several nuclear power plants, conducting inspections of nuclear records and documentation, and conducting QA audits of vendors and contractors at several nuclear stations. He also worked for a nuclear utility constructing a two unit nuclear power plant in various capacities including Manager of audits, Manager of Quality Assurance Administration, and other roles.

Mr. Lefman supported the Nuclear Regulatory Commission as a support contractor in various technical support tasks including conducting special inspections and reviews of NRC licensees, supporting special fire protection and PRA reviews, dispositioning allegations, and other support tasks. Mr. Lefman also authored and taught the NRC Technical Specialist Audit Training course to NRC headquarters and field staff, and also was involved in development of **NUREG/CR-5151**, ***Performance Based Inspections.***

Nicholas Bahr

Mr. Bahr has more than 23 years of professional experience in system safety, security, reliability engineering, and risk management, focusing on security and safety management systems and in depth technical risk assessments. Mr. Bahr was the Booz Allen Safety, Security, and Risk Management Transportation business leader for U.S. domestic and international clients that cover various market areas including: transportation, energy, manufacturing, and defense. Over his career, Mr. Bahr has conducted detailed technical risk assessments including new rail vehicle designs, design and operations of new safety technologies, implemented safety management systems in aviation regulatory oversight programs, and safety analyses for NASA space craft. Mr. Bahr developed the first-ever counter-terrorism assessment methodology for the transit industry. He led a team conducting counter-terrorism assessments of the 37 largest US transit properties. His client engagements range from risk strategy for federal and commercial senior executives to detailed risk assessments for front-line management. Mr. Bahr is author of the book *System Safety Engineering and Risk Assessment*, used as a graduate-level textbook at various universities. Currently, the FAA Flight Standards Services uses his book as their primary system safety model. Mr. Bahr is the Chair of the International Association for the Advancement of Space Safety's Committee for developing safety standards for space tourism. He also is the Working Group leader for developing risk management design standards for the American Public Transportation Association Security Steering Committee.

Frank C. Hood

Mr. Frank C. Hood is an in Environment, Safety, Health, and Quality (ESH&Q) with over 40 years of experience in managing ESH&Q activities for Battelle Memorial Institute and the Pacific Northwest National Laboratory. His experience includes conducting process analyses, incident and accident investigation, causal analyses, and risk evaluation experience in these areas:

- Hazard exposure and risk mitigation analyses of research and development (R&D), manufacturing, construction, and operational work processes;
- Management control systems analysis and root cause determinations;
- Incident/accident investigations to determine basic and contributing causes, determine corrective and preventive actions to preclude recurrence;
- Oversight of research and development using hazardous, toxic and nuclear materials;
- Hazardous and nuclear waste characterization and remediation;
- Quality, Environment, Safety and Health program management;
- Commercial nuclear power plant construction management;
- Quality oversight of medical device development and test programs;
- Controlled substance regulatory program management;
- Human research subjects program planning and assessment (including clinical trials); and

- Multi-media data generation, storage, analysis and results reporting, validation, and verification.

Mr. Hood also directed a corporate independent assessment program to ensure programmatic compliance with Battelle policies, regulatory requirements, and determine management process effectiveness. He conducted corporate-level investigations and management assessments to determine basic and contributing causal factors for incidents, accidents and performance deficiencies, and developed recommendations for corrective, preventive and improvement actions and directed a global Emergency Preparedness Program for the Battelle business complex, including development of enhanced provisions following 9-11. Mr. Hood developed, administered, and assessed the implementation of Battelle corporate ESHQ management policies, standards and guidance that support achievement of corporate performance objectives, and regulatory and contractual requirements.

II. TECHNICAL APPROACH

This report is based on the results of an ordered causal analysis process using the basic process described in DOE-NE-STD-1004-92, Root Cause Analysis Guidance Document (hereinafter referred to as the DOE Standard). The root cause analysis methods that were used included the following steps:

1. Problem identification
2. Determination of the significance of the problem
3. Identification of the basic (direct and contributing) causes (conditions or actions) immediately preceding and surrounding the problem
4. Identification of the reasons why the causes in the preceding step existed, working back to the root causes (the fundamental reason which, if corrected, will prevent recurrence of these and similar occurrences throughout the facility). This root cause analysis is the objective in the assessment phase.

The following root cause analysis methods were used collectively in this analysis:

Events and Causal Factor Analysis. Events and Causal Factor Analysis identifies the time sequence of a series of tasks and/or actions and the surrounding conditions leading to an occurrence. The results are displayed in an Events and Causal Factor chart that gives a picture of the relationships of the events and causal factors. **(See Figure 3.0)**

Cause and Effect Analysis. The Ishikawa diagram (or *fishbone diagram* or also *cause-and-effect diagram*) show the causes of a certain event. A common use of the Ishikawa diagram is in process analysis, to identify direct and contributing factors leading to an overall result. **(See Figure 3.1)**

Fault Tree Analysis. In the technique known as “fault tree analysis”, an undesired effect is taken as the root (‘top event’) of a logic tree and all concerns branch out from it. **The Fault Tree Analysis is depicted in Attachment C.**

The results from the various analyses were integrated into the assessment process and provided a consistent set of conclusions. This approach assured validation of conclusions through the use of separate logic techniques. NIST provided the Booz Allen Team with all the source documents (interviews, lab notebooks, procedures, photographs, etc) to conduct the root cause analysis. The

Booz Allen team reviewed and analyzed source documents provided by NIST, and only these documents were used to determine the root cause, contributing causes, and supporting causes. It should be noted that no interviews were conducted; only the interview notes that were gathered during the IRSC analysis and reporting were reviewed. The primary purpose of this root cause analysis was to validate the IRSC analysis and report.

The team members utilized the checklist developed in conformance with the DOE Standard to guide the root cause analysis and provide a common basis for assigning cause codes. The initial task was to evaluate the source documents to determine whether adequate information was available to "close the gaps" identified in the Gap Analysis Report provided to NIST in September 2008. It was noted that there are still some gaps in documentation to meet the DOE Standard, and these are highlighted in the **Gap Analysis Checklist** (see **Appendix D)**. The source documentation was used to determine root causes as defined in the DOE Standard. The primary root causes were documented; cause and effect diagrams and fault tree events and analyses were formulated and agreed upon with the subject matter experts.

Gap Explanation Summary

A checklist consisting of nearly 130 items was initially prepared based on requirements for information taken directly from DOE STD 1004-92. Throughout the root cause analysis and validation process, documents provided by NIST to the Booz Allen team were compared to the checklist to ensure collection and documentation of required information necessary to conform with the DOE standard. When documentation was received from NIST which fulfilled an item on the checklist, that item was considered to have been satisfactorily addressed. If documents obtained from NIST partially, but not completely addressed an item on the checklist, then the item was marked unsatisfactory by the Booz Allen team.

If no information was obtained from NIST that addressed a given item on the DOE checklist the item was categorized as a gap. The final DOE checklist included in Appendix B of this report contains a total of 46 gaps. However, it should be noted that 30 of the 46 gaps refer to the definition, creation and implementation of corrective actions. The establishment and implementation of corrective actions is something that will occur in the future using input form this, and other reports. The remaining 16 gaps essentially represent areas where information simply does not exist. These gaps are merely areas where the DOE Standard has specific requirements, but NIST did not conduct activities that could address the DOE Standard Root Cause requirements.

It should be noted that any omissions or gaps do not impact the root cause analysis findings or actions. These gaps are generally noted to demonstrate compliance with the DOE Standard and areas where insufficient information or data was available to determine the status. The conclusions in the report were determined from review of existing information provided by NIST, and the lack of the items noted in the checklist did not impact the completion of the root cause analysis.

III. RESULTS

1.0 ROOT CAUSE SUMMARY STATEMENT

The root cause of the plutonium spill and resulting contamination was the lack of management accountability and commitment at the highest levels at NIST to an effective operational safety culture at the Boulder NIST facility.

The key contributing causes were:

1. Inadequate management oversight
2. Inadequate operational safety management system
3. Poor organizational safety culture
4. Inadequate hazard analysis
5. Poor safety training
6. Inadequate emergency response

This condition was manifested in many ways throughout the four basic phases of the work cycle: Planning, Executing, Verifying, and Improving. There was a lack of management involvement and accountability in:

- Project hazard analysis
- Risk evaluation
- Emergency preparedness
- Material procurement
- Design of experiments
- Resource planning and allocation
- Training
- Lab set-up and management
- Conduct of work
- Chain-of-custody
- Mentoring
- Oversight
- Performance measurement and evaluation
- Handling hazardous material, particularly powders

All of these activities collectively contributed to the occurrence. The management structure, policies, lack of accountability, and lack of a demonstrated, pervasive, enforced, management system, is indicative of a poorly defined and executed management system and accountability.

2.0 FINDINGS AND DISCUSSION

Table 2-0: Root and Contributing Causes

Root Cause	Contributing Causes	Summary Findings
Lack of management commitment and accountability	1. Inadequate management oversight	▸ Little amount of senior management oversight between NIST-G and NIST-B ▸ Poor oversight by local managers ▸ No effective means of making senior managers accountable for safety issues ▸ Poorly defined safety roles and responsibilities ▸ Safety requirements not enforced
	2. Inadequate operational safety management system	▸ No formal operational safety management system in place ▸ SHED and RSO not sufficiently integrated into lab operations ▸ Safety data not sufficiently evaluated and trended
	3. Poor organizational safety culture	▸ Inadequate understanding of safety hazards ▸ Mixed lab use
	4. Inadequate hazard analysis	▸ No Hazard Review Committee (HRC) review or approval of use of Pu during experiment ▸ No formal hazard analysis performed on lab activities
	5. Poor safety training	▸ No Pu handling training courses ▸ Poor enforcement of safety course attendance prior to use of Pu sources ▸ Lack of training on the behavior and dispersal of powders
	6. Inadequate emergency response	▸ Slow and insufficient emergency reporting ▸ Lab not secured immediately

2.1 Inadequate Management Oversight and Accountability

Though safety is always the responsibility of front line management, senior management does have the responsibility to ensure that line management and staff meets NIST safety requirements and conducts their work in a safe manner. Analysis indicated that there was inadequate management oversight that lies primarily within three broad areas:

- NIST-Gaithersburg management oversight of Boulder operations
- NIST-Boulder management oversight of activities at the Boulder campus
- Principal Investigator oversight of individual experiment protocols and operations.

The operational safety management oversight activities are described in Section 2.2

2.1.1 NIST Gaithersburg Oversight of Boulder Operations

NIST Gaithersburg has ultimate management oversight responsibility of Boulder operations, and no evidence was found that a robust management oversight program was in place at the time of the incident. Although NIST has developed numerous hazardous material handling procedures (primarily through Health Physics Instructions (HPIs)) including the handling and use of radioactive material, it appears that there was no program in place to ensure it was implemented in Boulder operations. There were infrequent lab inspections or audits; the only audit data found was from 2005, which supports the observation that NIST Gaithersburg did not have adequate data to be aware if potential plutonium and other safety problems existed or not.

Although NIST Gaithersburg develops the HPIs for NIST use, the management system in place does not verify that the generic HPI information has been appropriately adopted for specific experiments in Boulder (such as the plutonium calibration experiment conducted). NIST management did not enforce, through audits, inspections, or analysis, safety requirements for the use of, or handling of radioactive sources. In particular, there is a requirement that a Hazard

Review Committee (HRC) shall be formed to review lab activities that handle hazardous activities, especially the handling of radioactive isotopes. No evidence was found that the HRC was formed to review, evaluate, and approve the proper handling of the plutonium source.

There was no evidence found that indicated that NIST Gaithersburg management held NIST Boulder management accountable for a robust and compliant safety oversight program. Based on the review of documents, it appears that NIST senior managers do not regularly request or require that Boulder managers produce evidence (audit-based or otherwise) to indicate that lab activities are conducted in a safe manner or meet internal NIST or NRC safety requirements. For example, NIST Gaithersburg does not regularly review Boulder data to ensure that staff has adequate safety training before handling radioactive sources. Review of interview data sources indicated that courses are given but rarely attended by staff. The training that was provided was superficial and not tailored to the needs of the intended audience.

2.1.2 Organizational Reporting Relationships

The organizational reporting relationships are not defined adequately to provide direct accountability and responsibility to allow for oversight of hazardous activities as depicted in the organization chart included in the IRSC report dated July 30, 2008. The Director of the NIST Boulder Laboratories does not have direct line management authority over programs in Boulder. Line management authority rests with corresponding Operating Unit (i.e. Laboratory) management for each of the activity areas. The current Director of Boulder has dual responsibilities for lab management as well as specific disciplines. The primary functions of the Boulder Director are to provide for the supervision of central support functions in Boulder and act as a central spokesperson and coordinator.

The Quantum Sensors Project team in Boulder was most directly involved with the plutonium contamination event. The Quantum Sensors Project Team reports to the Quantum Electrical Metrology Division Director in Gaithersburg. This organization does not provide adequate direct responsibility for a local Boulder direct to “own” the activities, and there is no evidence to indicate that Gaithersburg has instituted adequate oversight of these activities. Furthermore the Boulder Director of Safety, Environment and Health reports to the Division Chief, Safety, Health, and Environment Division (SHED) in Gaithersburg who reports to the Chief Human Capital Officer at NIST Gaithersburg. The organizational reporting relationship does not provide adequate visibility for safety issues at the appropriate management level in Gaithersburg.

2.1.3 Local Boulder Oversight of Internal Operations

The most significant Boulder oversight factor contributing to the plutonium incident was the lack of a rigorous Laboratory Operations Program for Boulder that defines Safety Operation System (SOS) and Radiation Safety (RS) requirements and responsibilities for line management and Principal Investigators. It was noted that there were:

- Less than adequate definition of Roles, Responsibilities, Accountability, and Authority (R2A2) to achieve SOS and RS provisions for research and support service functions
- Poor standards for mentoring, training, and establishing a safety culture for all research staff whether external or internal
- Lack of an effective technical training program
- The procurement process did not properly control radiological isotope purchases
- Lack of an approved, formal Work Plan System

- No hazard analysis process conducted
- Lack of apparent Boulder management review and visibility
- Poor lab work standards e.g., good lab practices (GLPs) and standard operating procedures (SOPs)
- Inadequate radioactive material (RAM) lab operating standards
- Poor principle investigator (PI) and line manager oversight
- Inadequate lab space management standards and accountability
- Little or no performance standards, monitoring, reporting and trend analysis
- Lack of a performance improvement program

The apparent lack of NIST Boulder management's oversight activity as well as lack of a safety culture, contributed to the plutonium spill and subsequent contamination. If the NIST Boulder lab activities had been properly managed then it is possible that the spill could have been prevented or the contamination consequences adequately mitigated. NIST Boulder management did not ensure that the experimenters were appropriately qualified to conduct a minimally supervised experiment that used a plutonium source. The management system did not ensure that a work plan for the conduct of hazardous experiments was in place, that experimenters had proper qualifications and training, and that there was adequate oversight of the experiments and the staff at all times. There were no apparent management provisions to monitor the experimenters at all times, and ensure that periodic radiation safety checks were provided (particularly during non-traditional work hours such as evening, and weekends).

Because there are no regularly scheduled safety audits of the laboratory, there is little evidence of a closed-loop corrective action system that could have identified the lab safety deficiencies and track their corrections to closure. Without a formal, regular audit process, the Boulder Director of Safety, Environment and Health and RSO did not have adequate safety data on hand to understand that there were serious deficiencies in how to handle a plutonium source. Boulder management did not establish a proactive management system to identify hazards and ensure provisions to address the hazards and responses.

Although NIST Gaithersburg sets the safety standards and requirements for all activities involving handling of radioactive sources, those safety requirements (HPIs) were not tailored to Boulder operations or enforced. There appeared to be poor administrative control and oversight of the handling of the plutonium sources. In addition, there was little management accountability for those that did not comply.

The Boulder Radiation Safety Officer (BRSO) and the Principal Investigator (PI) were not involved enough in oversight of the experiment, particularly considering the specific hazard posed by use of powdered plutonium source material. The BRSO only got involved after contact by the PI after discovery of a serious situation. The BRSO reports to the Boulder Director of Safety, Environment and Health who reports to the NIST Gaithersburg Division Office of Safety, Health, and Environment.

2.1.4 PI Oversight of Individual Experiment

As stated earlier, though management oversight is responsible to ensure that all safety procedures are adequately developed, implemented, and enforced, it is line management's responsibility to ensure the experiment does not have adverse safety impact on staff in the laboratory area. There are no apparent requirements for development of specific work plans to detail how experiments will be carried out, how hazardous substances will be handled, and the appropriate staffing to monitor the experiments.

The plutonium source was not adequately controlled and safeguarded; the plutonium was not stored, handled, maintained, nor disposed of in a proper and safe fashion. The researchers did not use appropriate personal protection equipment (PPE), such as gloves or tongs to safely handle the material. The researchers did not understand the safety hazards related to plutonium handling because neither they nor any other Boulder entity conducted a hazard analysis on the experiment's hazards or the proper handling of the plutonium source. Neither SHED nor the RSO conducted a hazard analysis, thus losing the opportunity to inform the researchers of their risks in the experiment. Furthermore there was lack of oversight by the PI and the RSO at periodic intervals to ensure that the experiments were conducted safely, and the plutonium was under control at all times including evenings and weekends.

2.1.5 Individual Researcher Accountability

The NIST IRSC report detailed the series of events and contributing causes to the plutonium spill. The individual researcher also bears culpability for the accident. There was inadequate experiment planning and basic description of the experiments, the staff, the tools, the hazards, and the appropriate procedures to implement. The researcher did not follow any protocol, and appeared to perform work without any specific guidance, requirements, and oversight. The researcher did not set up the experiment with safety in mind. The equipment was assembled in a crowded, multi-use laboratory facility, was not laid out well, and did not offer proper protection to personnel and equipment. The researcher breached the plutonium container and caused the plutonium powder to spill onto surfaces and become airborne. The researcher was not aware of any requirements on responding to an accident, notifications, and containing the spill.

Lack of personal control and understanding of the hazards involved with plutonium handling or of the severity of the incident itself, led the researchers to spread the contamination outside the immediate work area. In addition, because the experiment was in a mixed-use lab and the other experimenters did not know plutonium was being handled in the lab, other lab personnel were at significant risk.

2.2 Inadequate Operational Safety Management System

The NIST Safety Operational System (SOS) provides requirements for ensuring safety practices in Gaithersburg and Boulder. The policy states that "The safety of everyone who works at or visits NIST is a top priority. The NIST goal is zero lost-time incidents/accidents in a culture of sustained performance excellence…. The keys to effective line safety performance are management procedures that create a culture of safety, while defining and expecting accountability for results and minimizing hazards."

Safety is always the responsibility of front line managers and staff. The safety organization is responsible to support NIST employees to help them perform their work in a safe manner. However, no evidence was noted that a formal Boulder-wide safety program was in place. There is no central system safety program plan that explains and details Boulder's safety program. Though Boulder does use the NIST HPIs, they are generic and have not been modified for use at Boulder, and did not address handling of plutonium. No Boulder-specific safety manual exists that serves to inform all Boulder employees of the safety hazards that they can encounter in their day-to-day activity. There was little evidence found of regular safety inspections or audits.

Because there are few safety audits, no evidence was found of hazard tracking, trending, and risk resolution. In addition, no evidence was found that the Boulder safety program verifies that safety requirements are met, that lab activities are done safely, and that staff is adequately safety-trained before starting a hazardous experiment using plutonium.

Although the plutonium was purchased through appropriate channels and the approval processes, there was no formal process in place that ensures that staff that handle the plutonium source are adequately safety-trained, that appropriate safety procedures are in place, that a hazard analysis has been conducted, and that corrective actions are verified to be closed before the experiment begins.

The lack of a defined and effective Laboratory Safety Operational Program that implements SOS and Radiation Safety (RS) provisions for NIST-Boulder line was manifest in the following observations:

- No apparent definition of roles, responsibilities, accountability and actions to meet the Safety Operational System and Radiation Safety administrative manual provisions for safety and health functions
- Lack of an effective safety training program
- Inadequate radiation safety discipline, e.g., work planning and barrier control
- Lack of work plans and tailored safety practices
- Less than adequate chain-of-custody discipline
- Less than adequate Lessons Learned program and external interface with relevant databases
- Lack of a continuing performance management system focused on obtaining metrics, establishing Key Performance Indicators (KPIs) for safety, and corrective action system based on establishing root causes and lessons learned

Discussion:

The results of the root cause analysis of the plutonium spill incident at the NIST Boulder facility include basic and contributing causes linked in some way to all elements of Safety Operational System requirements, which demonstrate that there are basic processes, program and procedural weaknesses as well as inadequate management involvement in oversight of, and accountability for, work being done. Laboratory operations and the laboratory safety operations programs need to be strengthened significantly in both form and function. The two programs need to operate in an integrated manner with autonomous but mutual functional accountability. Additionally it was noted that there was a lack of detail and specificity in the SOS and other procedures to enable staff to recognize their specific roles and actions to execute the requirements. Item-by-item flow-down of SOS and RS provisions is needed in formal Laboratory Operations and Laboratory Safety Operations programs that describe R2A2s for all managers, researchers, assistants, support personnel and workers.

A method of performance measurement to enforce operational accountability, with safety success factors for all managers and staff, is needed to promote safety priorities.

An integrated oversight process is needed to assure line and functional awareness of operational performance, and to encourage cooperative performance improvement initiatives.

2.3 Poor Organizational Safety Culture

Most major government and large private sector organizations have some sort of established safety culture to define the organization mission and policy with regard to defining safety goals and implementation of safety objectives. Analysis of source documents indicated that NIST Boulder did not establish nor implement a safety culture. Senior NIST management in both locations have not promoted nor proclaimed a positive safety culture through actions that illustrate why safety is important at NIST. A positive safety culture is a combination of the appropriate management infrastructure in place to support safety actions and the commitment of leadership and staff to be safety-conscious at all times. There was no evidence that either of these activities were in place during the incident. Experimenters typically do not give safety briefings before conducting experiments with hazardous materials. No safety briefing was given to/by the experimenters handling the plutonium source. Additionally, in a well defined an implemented safety culture, employees' awareness of safety requirements and reporting safety concerns and hazards are expected and demonstrated. The specific observations from analysis of source documents to support this decision include:

- Lack of appropriate signage warning of safety hazards and issues in the area
- Outdated policies and procedures (lack of revisions over a long period of time)
- Lack of communication of management expectations with regard to implementation of safety expectations
- Lack of training and attendance at mandatory training sessions
- Lack of procedure implementation
- Lack of respect and confidence between research organizations
- Lack of qualified subject matter staff and expertise in the Safety, Health, and Environment area
- Lack of safety precautions and outmoded facilities (eyewash stations, safety hoods, ventilation systems)

OSHA provides this definition and expectations of a safety culture:

"***What is a safety culture - how will it impact my company?***
Safety cultures consist of shared beliefs, practices, and attitudes that exist at an establishment. Culture is the atmosphere created by those beliefs, attitudes, etc., which shape our behavior. An organization's safety culture is the result of a number of factors such as:

- *Management and employee norms, assumptions and beliefs;*
- *Management and employee attitudes;*
- *Values, myths, stories;*
- *Policies and procedures;*
- *Supervisor priorities, responsibilities and accountability;*
- *Production and bottom line pressures vs. quality issues;*
- *Actions or lack of action to correct unsafe behaviors;*
- *Employee training and motivation; and*
- *Employee involvement or "buy-in."*

In a strong safety culture, everyone feels responsible for safety and pursues it on a daily basis; employees go beyond "the call of duty" to identify unsafe conditions and behaviors, and *intervene to correct them. For instance, in a strong safety culture any worker would feel comfortable walking up to the plant manager or CEO and reminding him or her to wear safety glasses. This type of behavior would not be viewed as forward or over-zealous but would be valued by the organization and rewarded. Likewise coworkers routinely look out for one another and point out unsafe behaviors to each other.*

A company with a strong safety culture typically experiences few at-risk behaviors, consequently they also experience low accident rates, low turn-over, low absenteeism, and high productivity. They are usually companies who are extremely successful by excelling in all aspects of business and excellence."

In an Institute for Nuclear Power Operations (INPO) document entitled "*Principles for a Strong Nuclear Safety Culture" dated November 2004,* safety culture is defined as: "***Safety culture: An organization's values and behaviors—modeled by its leaders and internalized by its members—that serve to make nuclear safety the overriding priority."*** A key attribute from this report is:
"***Leaders demonstrate commitment to safety. Executive and senior managers are the leading advocates of nuclear safety and demonstrate their commitment both in word and action***." The nuclear safety message is communicated frequently and consistently, occasionally as a stand-alone theme. Leaders throughout the nuclear organization set an example for safety.

2.3.1 Attributes of a Safety Culture:

INPO describes the primary attributes and actions that are manifest in an organization with a robust nuclear safety culture which include:

- **"**Managers and supervisors practice visible leadership in the field by placing "eyes on the problem," coaching, mentoring, and reinforcing standards. Deviations from station expectations are corrected promptly.
- Management considers the employee perspective in understanding and analyzing issues.
- Managers and supervisors provide appropriate oversight during safety-significant tests or evolutions.
- Managers and supervisors are personally involved in high-quality training that consistently reinforces expected worker behaviors.
- Leaders recognize that production goals, if not properly communicated, can send mixed signals on the importance of nuclear safety. They are sensitive to detect and avoid these misunderstandings.
- The bases, expected outcomes, potential problems, planned contingencies, and abort criteria for important operational decisions are communicated promptly to workers.
- Informal opinion leaders in the organization are encouraged to model safe behavior and influence peers to meet high standards.
- Selection and evaluation of managers and supervisors consider their abilities to contribute to a strong nuclear safety culture."

2.4 Inadequate Hazard Analysis

No evidence was found that a rigorous, systematic hazard analysis process is in place. None was performed on the plutonium experiment. Based on document reviews and interviews it appears that neither SHED nor the RSO conducted any hazard analysis related to plutonium handling and use. The lack of hazard analysis and work planning did not provide adequate information to management and researchers in Boulder to enable them to be aware of the hazards, understand the hazards related to the specific experiment, and take proactive actions. In particular, there were no formal processes to:

- Identify the hazards related to handling and using plutonium powder or other radioactive sources
- Evaluate the hazards and determine the risks related to the plutonium activities
- Manage the risks so that personnel are appropriately protected from a significant incident
- Develop specific work plans, develop safety plans and prevention and response plans
- Ensure appropriate staffing by discipline and work area.
- Ensure specific training on specific procedures and processes

2.5 Poor Safety Training

Based on review of the source documents, it is evident that the researchers did not attend any safety training courses prior to using the plutonium source. Although NIST Boulder does have a very general and broad course on radiation, it is inadequate because it does not detail the specific hazards and appropriate safe handling procedures that should be followed while using radiation sources. Additionally, some researchers had signed up to take safety training classes, but did not attend the training class, and there was little or no follow-up to ensure attendance. In some instances, only three out of thirty people actually participated in the training course. There is no requirement to take refresher safety courses. Some of the basic training issues identified in the source documents that support this contention include:

- The formal radiation safety training provided to staff members is very basic, limited, and inadequate for the type of research applications
- New researchers were given general instructions on the detector system but no specific instructions on handling the radioactive sources
- Researchers were unfamiliar with NIST policies covering the use of radioactive materials
- Specific hazard information, handling instructions, or control procedures were not communicated to or known by the workers
- A worker did not have any training or experience to prepare him to handle a source or respond to a contamination event
- Lack of training on reporting or responding to contamination events and understanding on the behavior of powders and dispersal properties

2.6 Inadequate Emergency Response

The analysis of the source documents and data support the conclusion that NIST Boulder did not establish nor implement an emergency notification and rapid response system to deal with safety hazards. A rapid and robust emergency response could have significantly mitigated the contamination. The first action—reporting the incident—was inadequate:

- The lab personnel did not follow emergency response procedures and seemed unsure of or how to report the incident
- The lab was not adequately secured until hours after the incident

- Researchers minimized the hazard severity, were slow to report the incident, and reported little detail of the accident
- Other staff of the mixed-use lab were not informed of the incident nor severity of the consequences on a timely basis
- There was a lack of personnel protective equipment and emergency equipment in the lab that could have minimized the hazards or mitigated the contamination
- There was a lack of an emergency plan that provided instruction to staff on reporting emergencies and specific proper actions
- There was no evidence to indicate that staff received emergency response training or participated in any emergency drills related to handling hazardous materials.

In general terms, the provisions of NIST Administrative Manual, Subchapter 12.01, Safety Operational System (SOS), and Subchapter 12.03, Radiation Safety, adequately define the roles, responsibilities, actions and accountabilities (R2A2s) as well as operational principles and goals for an effective safety process.

The set of Health Physics Instructions established after the plutonium incident acknowledges the subject matter coverage needs for the Boulder facility, but the instructions are generic in nature, do not describe specific responsibilities and requirements, and require tailoring to application needs. Furthermore these procedures require review by subject matter experts and line managers before they can be implemented effectively. The focus for accountability needs to be directed to line managers and workers instead of assigned as adjunct duties to overhead staff.

2.7 Basic and Contributing Causes

As previously stated, the primary root cause of the plutonium incident was the lack of management accountability and commitment to achieve an effective operational safety working environment.

The more significant contributing causes to the plutonium incident were:

- Lack of a rigorous laboratory operations program for NIST-Boulder that implements SOS and RS line management and researcher provisions:
  - Less Than Adequate (LTA) definition of R2A2s to achieve SOS and RS provisions for research and support service functions
  - Lack of an effective technical training program
  - LTA procurement process for special and hazardous material
  - Lack of an approved, formal work plan system:
    - LTA Hazard Analysis
    - LTA management review and visibility
    - LTA lab work standards e.g., good lab practices (GLPs) and standard operating procedures (SOPs)
  - Inadequate radioactive material (RAM) lab operating standards
  - LTA principle investigator (PI) and line manager oversight
  - LTA lab space management standards and accountability
  - LTA performance standards, monitoring, reporting and trend analysis
  - LTA performance improvement program

- Lack of an ordered Laboratory Safety Operational Program that implements SOS and Radiation Safety (RS) provisions for NIST-Boulder line and functional managers, researchers and staff members;
  - LTA definition of R2A2s to achieve SOS and RS Administrative Manual provisions for safety and health functions
  - Lack of an effective safety training program
  - LTA radiation safety discipline, e.g., work planning and barrier control
  - LTA RAM use review process
  - LTA RAM chain-of-custody discipline
  - LTA Lessons Learned program and external interface with relevant databases

Recommendations for addressing these issues are provided for consideration in Appendix E of this report.

3.0 Initial Event Mapping

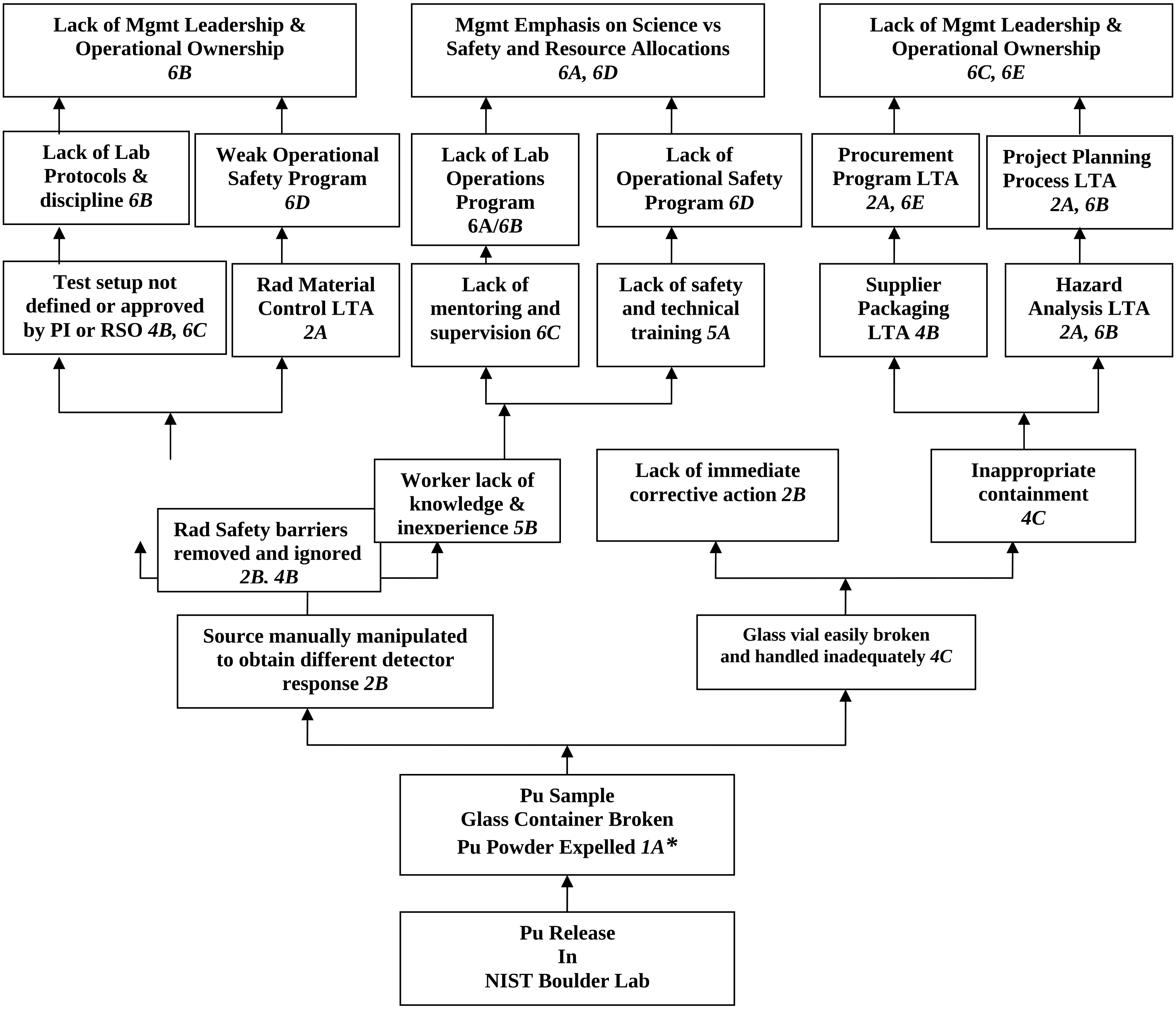
A chain of Causes/Incident Tree Diagram (refer to Figure 3.0) was developed for initial event mapping to provide a general perspective for approaching the evaluation of the plutonium spill at Boulder. The methodology started with the effect and the major groups of causes and then asked for each branch, “Why did this happen? What caused this?” The tree diagram is a graphic display of the causal analysis method known as the *Five Why’s.* It displays the layers of causes, looking in-depth for the *root* cause(s). This analysis provided a validation base for the more rigorous causal analysis methods used in this report.

The plutonium spill, personnel exposure and facility contamination resulted from failure to follow prudent material handling practices due to worker lack of experience, knowledge and training; inadequate design of experiment, hazard analysis and risk management, and work planning; control of radioactive material; inadequate involvement of the PI and line managers; and inadequate infrastructure support programs and services. All of these conditions and factors could have been avoided by a strong management commitment to and accountability for a preventive safety process.

Cause codes defined in Appendix A of DOE-NE-STD-1004-92, Root Cause Analysis Guidance Document were assigned to each element of the Incident Tree diagram to provide a framework for more detailed causal analyses.

The handling of the glass vial was identified in the event chain mapping as a contributing event. However, it could not be determined whether the glass vial was a problem due to handling, age, or condition of the vial due to other uses.

Figure 3.0: NIST- Boulder Plutonium Incident Tree Diagram



*** The numbers refer to root causes linked to the DOE Standard**

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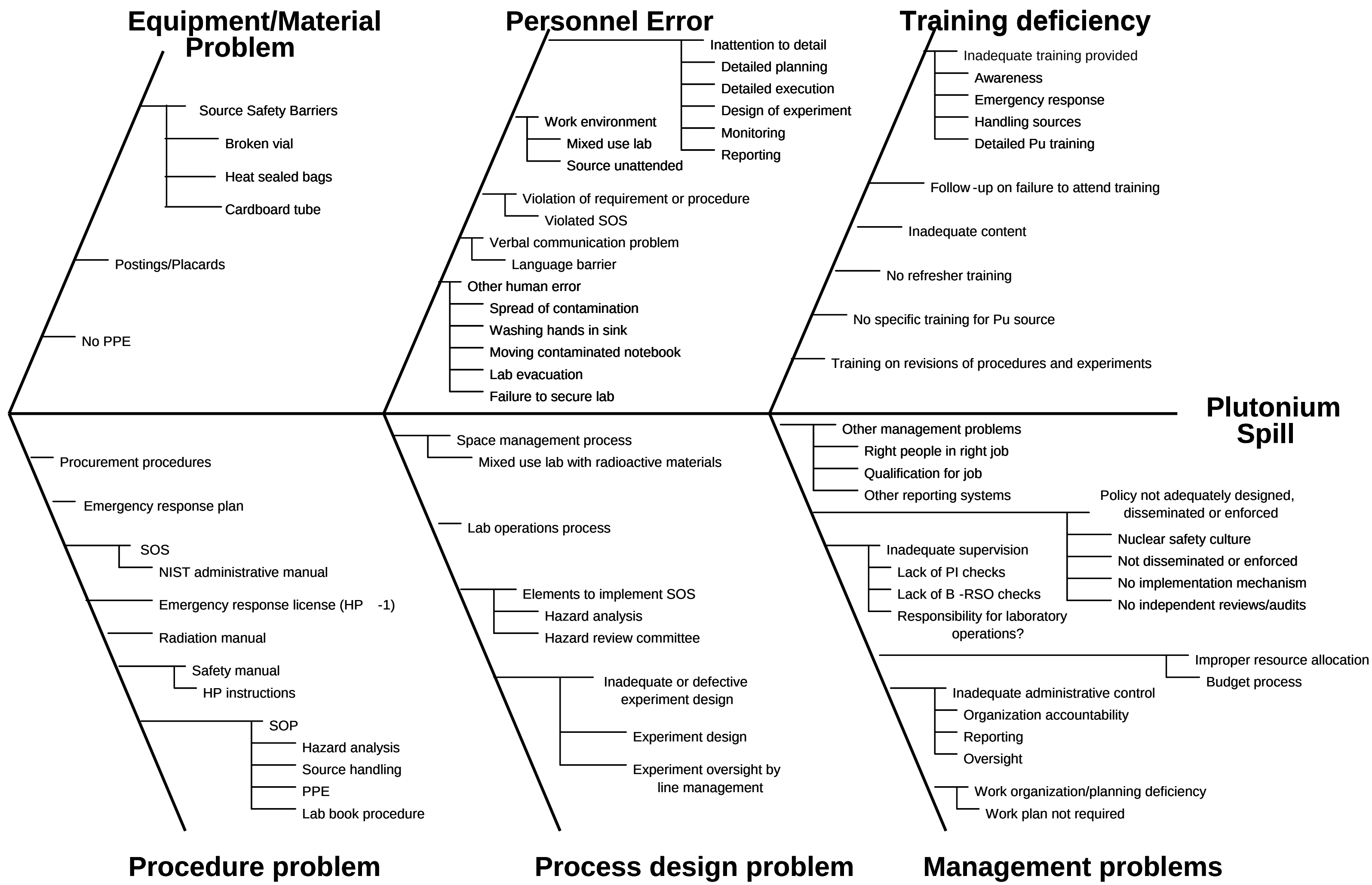
Figure 3.1: Cause and Effects Analysis (fishbone diagram)



IV. EVALUATION OF IRSC REPORT

The IRSC report dated July 30, 2008 provided a detailed factual report of the incident with supporting photographs, analyses, and results. The root cause, direct causes, and contributing causes were well defined, documented, and conclusions supported. Our analysis of the source documents along with our root cause analysis conducted in accordance with DOE-NE-STD-1004-92 guidance supports the root cause identified in the IRSC report attributed to "A failure in the existing NIST safety management system as it was applied to the detector project being carried out by the researchers in Boulder." The root cause defined in this report is broader and attributes the failure in the existing NIST safety management to the lack of management accountability and commitment at the highest levels at NIST to an effective operational safety culture at NIST's Boulder facility. The approach and findings identified in the IRSC report were validated by the Booz Allen Hamilton team, and were the basis for our fault tree analysis and assignment of cause codes. Booz Allen Hamilton included a comparison of the IRSC report finding to the findings identified in this report in a **Comparison Matrix** in **Attachment D**. The obvious areas that were missing from the IRSC report were the detailed root cause analysis, the development of a corrective action response and comprehensive tracking, development of a trending and performance management system, and communication of results. The recommended actions appear to be valid and should be considered along with the recommendations in this report to formulate a comprehensive corrective action plan that can address the findings as well as the NRC confirmatory action letter.

APPENDIX A: REVIEWED NIST SOURCE DOCUMENTS

Item #	Source Document Title
1	"Basic Radiation Safety", Training Document
2	2006 Health Physics Instructions
3	2006 NIST Annual Report Addendum: NIST/Boulder Radiation Safety
4	2008 Health Physics Instructions
5	Radiation Safety Training power point presentation
6	Collection of documents regarding Pu sample acquisition including email exchanges between relevant parties
7	EEEL Division Safety Walkthrough notes
8	EEEL Division Safety Walkthrough schedule
9	EEEL Quarterly Safety Reports
10	Email exchange answering questions regarding the incident
11	Email exchange between NIST Boulder and NBL laboratory confirming shipment of Pu samples
12	Event timeline developed from video surveillance system
13	Health Education Programs List
14	Health Physics CY2007 Annual Report
15	Incident Report
16	Incident Report
17	Incident Report
18	Incident Report
19	Incident Report
20	Independent Oversight Special Review of Safety at the National Institute of Standards and Technology Boulder Laboratories
21	Internal Investigation of Plutonium (Pu) Incident that Occurred at NIST Boulder June 9, 2008.
22	IRSC Report Appendix A: Detail Chronological Description of Event
23	IRSC Summary Review of the Boulder Radiation Safety Program
24	Laboratory Safety Manual Chapters 1-7,9-11
25	Log of events captured by video surveillance systems
26	Memorandum: IRSC recommendations on Boulder license
27	MINUTES: Ionizing Radiation Safety Committee Meeting October 20, 2004
28	MINUTES: Ionizing Radiation Safety Committee Meeting. 2004 Annual Meeting. January 14, 2005.
29	MINUTES: Ionizing Radiation Safety Committee Meeting. 2005 Annual Meeting. January 19, 2006.
30	MINUTES: Ionizing Radiation Safety Committee Meeting. January 17, 2007.

Item #	Source Document Title
31	NCNR Personal Protective Equipment Policy
32	NIST Administrative Manual Subchapter 12.01: Safety Operational System (SOS)
33	NIST Administrative Manual, Subchapter 12.02. Accident Investigation and Reporting (1998)
34	NIST Administrative Manual, Subchapter 12.03. Radiation Safety
35	NIST Boulder Laboratories Occupant
	Emergency Plan. January, 2003.
36	NIST Good Work Practice Guide for Area Radiation Surveys
37	NIST Good Work Practice Guide for Contamination Control
38	NIST Good Work Practice Guide for Decontamination
39	NIST Good Work Practice Guide for Guide Hall Users and Occupants
40	NIST Good Work Practice Guide for NBSR Beam Tube Experimenters
41	NIST Good Work Practice Guide for Personal Radiation Dosimeters
42	NIST Good Work Practice Guide for Radiation Facilities (Bldg 245)
43	NIST Good Work Practice Guide for Radioluminous Materials
44	NIST Good Work Practice Guide for Sealed Sources
45	NIST Good Work Practice Guide for the Cold Neutron Depth Profiling Facility
46	NIST Good Work Practice Guide for the Use of Laboratory Hoods
47	NIST Good Work Practice Guide for the Use of Unsealed Sources
48	NIST Good Work Practice Guide for the Use of X-ray Producing Machines
49	NIST Good Work Practice Guide for Users of Deuterated Compounds
50	NIST Good Work Practice Guide for Using Radiation Survey Instruments
51	NIST Good Work Practice Guide for X-ray Diffraction and X-ray Fluorescence Units
52	NIST Health and Safety Instructions
53	NIST Ionizing Radiation Safety Committee Initial Report of Plutonium Contamination at NIST Boulder
54	NIST Personal Protective Equipment Policy and PPE Template May 31, 2005
55	NOAA Web-Based Training/Menu Shot
56	Notes taken on 1/17/07 regarding changes to the NIST Boulder NRC license
57	Notes outlining Pu spill response
58	NRC Specific License Amendment Request #27
59	NRC Specific License Amendment Request #28
60	NRC Specific License Amendment Request #29
61	Personnel interview notes
62	Photographs laboratory notebook pages
63	Post Incident Laboratory Photographs 85 – 116 (6/19)

Item #	Source Document Title
64	Post Incident Laboratory Photographs 1 – 84 (6/13 and 6/14)
65	Post Incident Laboratory Radiological Survey Reports
66	Preliminary Report to NIST IRSC Concerning Pu Incident in NIST Boulder
67	Radiation Response Surveys
68	Radiation Safety at NIST: Signage
69	Radiological Materials Training Presentation
70	Radiological Survey Results
71	Report of a Peer Review Audit of the National Institute of Standards and Technology's Radiation Protection Program for NRC License SNM 362.
72	Scan of the detector spectrum obtained during experiment
73	Scan of laboratory notebook
74	Scans of laboratory notebooks
75	Statements made by NIST personnel regarding the Pu spill at NIST Boulder
76	Summary of interview
77	Summary of Radiation Training
78	U.S. Government Motor Vehicle Operator Identification
79	Video Tapes and Slides Available from the Safety Office (2007)

APPENDIX B: GAP ANALYSIS CHECKLIST

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
1.1	Outline what happened step by step	Section 3, Paragraph 2			Incident Chronology given in IRSC report Appendix A basically acceptable. Other timelines also provided.
1.2	Identify the problem (condition, situation, or action that was not wanted or planned)	Section 3, Paragraph 2			Release event was described. Specific exposure details were not addressed.
1.3	Determine what program element(s) should have prevented the occurrence (was it lacking or did it fail?)	Section 3, Paragraph 2			IRSC report recommendation C.2 addresses need to improve Safety Culture through line mgmt. LTA procedures, Rad Safety & Training programs.
1.4	Investigate why situation was permitted to exist	Section 3, Paragraph 2			A Key Contributing Cause identified collegial working environment and lack of Safety Culture.
1.5	Identification of effective corrective actions including:	Section 3, Paragraph 3			IRSC REPORT IDENTIFIES corrective actions
1.5.1	Effective management emphasis on the identification and correction of problems that can affect human and equipment performance, including assigning qualified personnel to effectively evaluate equipment/human performance problems, implementing corrective actions, and following up to verify corrective actions	Section 3, Paragraph 3		X	No evidence as to extent of management involvement and emphasis. No evidence of formal mechanism for implementing corrective actions and providing verification.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
1.5.2	Development of administrative procedures that describe the corrective action process, identify resources, and assign responsibility	Section 3, Paragraph 3			IRSC report Recommendation F tasks NIST to define corrective actions, assign responsibilities, track progress to complete and assess effectiveness. NIST SOS needs follow-down procedures..
1.5.3	Development of a working environment that requires accountability for correction of impediments to error-free task performance and reliable equipment performance	Section 3, Paragraph 3			IRSC report Recommendation C.2 addresses need to integrate safety into line mgmt R2A2s. Focus was on safety; entire management program needs over-hauled to stress quality.
1.5.4	Development of a working environment that encourages voluntary reporting of deficiencies, errors, or omissions	Section 3, Paragraph 3			Stated in NIST SOS, but not specifically addressed in a formal system.
1.5.5	Training programs for individuals in root-cause analysis	Section 3, Paragraph 3			Stated in NIST SOS, but not specifically addressed in a formal system. Recommended external root cause analysis.
1.5.6	6) Training of personnel and managers to recognize and report occurrences, including early identification of significant and generic problems	Section 3, Paragraph 3			Not specifically addressed by administrative system. A key element of a healthy Safety Culture. IRSC report
1.6	Development of programs to ensure prompt investigation following an occurrence or identification of declining trends in performance to determine root causes and corrective actions	Section 3, Paragraph 3			Several indicators this could have been a recommendation: delay in establishing Investigation Team, no mention of Safety Trend data, performance stds, etc. Called for detailed Root Cause Analysis. IRSC report

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
1.7	Adoption of a classification and trending mechanism that identifies those factors that continue to cause problems with generic implications	Section 3, Paragraph 3		X	Performance Analysis program conspicuous in its absence; IRSC Report had macro view, but not specifically addressed. No documentation could be found
1.8	Report produced that summarizes findings, lists causal factors and lists corrective actions?	Section 7, Phase IV			Covered by IRSC report
1.9	Cause selection focused on programmatic and system deficiencies and avoided simple excuses such as blaming the employee	Section 5.1, Subsection 2, Paragraph 2			IRSC report was objective.
1.10	Corrective action recommendations selected to prevent recurrence, reasons why they were selected are included with an explanation as to how they would prevent recurrence	Section 3, Paragraph 1			Broad CA recommendations with specific need for detailed Root Cause Analysis covers this.
2.1	Data collection carried out immediately following identification of incident	Section 4, Paragraph 1			June 9 – Incident June 11 – EEEL Investigation started June 22 – IRSC Investigation started
2.2	Information collected consists of conditions before, during and after the incident	Section 4, Paragraph 1			Worker statements received on June 19 provide insights into working conditions
2.3	Information collected includes personnel involvement, environmental factors and other information having relevance to the condition or problem	Section 4, Paragraph 1			Information collected generally good.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
2.4	For serious cases: environment was photographed	Section 4, Paragraph 1			Scene had already been disturbed. True depiction not obtained. Multitude of post incident photographs provided
2.5	Every effort was made to preserve physical evidence	Section 4, Paragraph 1			PI and Worker 1 compromised evidence. IRSC noted the steps taken after notification
2.6	Incident participants and other knowledgeable individuals identified	Section 4, Paragraph 1			Incident participants and staff secondary to the incident identified in various documents.
2.7	Data is verified to ensure accuracy	Section 4, Paragraph 2		X	No data verification effort referenced.
2.8	Efforts made to retain physical evidence such as area quarantine or tagging and segregation of pieces or material for failed equipment and components	Section 4, Paragraph 2			Effort was evidently made.
2.9	Activities related to the occurrence considered: (1-4)	Section 4, Paragraph 3			Procurement, work plan and prep, Incident and reaction activities considered. Covered in IRSC report
2.9.1	(1) Initial or recurring problems considered	Section 4, Paragraph 3		X	Stated need for Formal Root Cause Analysis. Recognized need for formal, independent Assessment.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
2.9.2	(2) Hardware (equipment) or software (programmatic-type-issues) associated with the occurrence considered	Section 4, Paragraph 3			Covered to extent needed. Lack of Work Plan, SNM experience, training severely compromised credibility.
2.9.3	(3) Recent administrative program or equipment changes considered	Section 4, Paragraph 3		X	Factors considered included out-of-date procedures and un-implemented policy changes. Have not seen evidence of administrative program changes except for updates to the NIST Health Physics Instruction Manual.
2.9.4	(4) Physical environment or circumstances considered	Section 4, Paragraph 3			Cursory coverage to observe work space and equipment inadequacies.
2.10	Conduct interviews with people most familiar with the problem and gather statements	Section 4, Paragraph 4			Workers and PI directly involved were interviewed.
2.11	Conduct "walk-throughs"	Section 4, Paragraph 4			Documentation provided of EEEL safety walkthroughs. In IRSC report
2.12	Interview others with past job performance experience	Section 4, Paragraph 4	X		Not addressed. First time this particular source material used at Boulder.
2.13	Review relevant records/documents as reference to support root cause analysis, recording appropriate dates and times associated with the occurrence:	Section 4, Paragraph 4			Available (although inadequate) records were reviewed. Chronological history developed as well as could be expected. In IRSC report

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
2.13.1	Laboratory books	Section 4, Paragraph 4			Received scans of several laboratory books.
2.13.2	Operating logs	Section 4, Paragraph 4		X	No operating logs in evidence.
2.13.3	Correspondence	Section 4, Paragraph 4			Received records of multiple email conversations
2.13.4	Inspection/surveillance records	Section 4, Paragraph 4		X	No inspection records for the laboratory and experiment involved. Did receive timelines based on video surveillance.
2.13.5	Maintenance records	Section 4, Paragraph 4		X	No maintenance records in evidence
2.13.6	Meeting minutes	Section 4, Paragraph 4			IRSC meeting minutes provided.
2.13.7	Computer process data	Section 4, Paragraph 4			Mentioned recorded data record review. Detector data plot provided.
2.13.8	Procedures and instructions	Section 4, Paragraph 4			Workers unaware of procedures. No written experimental procedure. Lack of detailed procedures
2.13.9	Vendor manuals	Section 4, Paragraph 4	X		Primary equipment built in-house.
2.13.10	Drawings and specifications	Section 4, Paragraph 4		X	No Work Plan, so no drawings or specs.
2.13.11	Functional retest specifications and results	Section 4, Paragraph 4	X		No conduct-of-experiment sequences – no work Plan,
2.13.12	Equipment history records	Section 4, Paragraph 4	X		Anecdotal mention of equipment used.
2.13.13	Design basis information	Section 4, Paragraph 4	X		No Work Plan or design-of-experiment.
2.13.14	Safety Analysis Report (SAR)/technical specifications	Section 4, Paragraph 4	X		No hazard evaluation or risk analysis available to review..
2.13.15	Related quality control evaluation reports	Section 4, Paragraph 4			Some inspection and safety reports provided, however, they are either several years old or do not relate to the experiment

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
2.13.16	Operational safety requirements	Section 4, Paragraph 4			Operational safety protocols exist, but are not adequately implemented noted in IRSC report
2.13.17	Safety Performance Measurement System/Occurrence Reporting and Processing System (SPMS/OPRS) reports	Section 4, Paragraph 4		X	Safety Performance Measurement System not in evidence. Not identified in IRSC report, do data noted
2.13.18	Radiological surveys	Section 4, Paragraph 4			Post event survey reports provided
2.13.19	Trend charts and graphs	Section 4, Paragraph 4		X	No Safety Performance Data.
2.13.20	Facility parameter readings	Section 4, Paragraph 4		X	No mention of facility parameter survey data.
2.13.21	Sample analysis and results (chemistry, radiological, air, etc.)	Section 4, Paragraph 4		X	No mention of up-to-date sample analysis prior to Incident.
2.13.22	Work orders	Section 4, Paragraph 4		X	No mention of WO system.
2.14	Evaluate the need for laboratory tests such as destructive or nondestructive failure analysis	Section 4, Paragraph 4		X	Sample not physically suitable for intended use, but used anyhow. No evaluation for testing needs in evidence.
2.15	View physical layout of system, component or work area; develop layout sketches of the area; take photographs to better understand conditions	Section 4, Paragraph 4			Work area drawings and pictures provided.
2.16	Determine if operating experience information exists for similar events at other facilities	Section 4, Paragraph 4		X	No evidence such an investigation was conducted.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
2.17	Review equipment supplier and manufacturer records to determine if correspondence has been received addressing this problem	Section 4, Paragraph 4	X		Primary equipment developed in-house.
3.0	Analyze data to identify causal factors	Section 5, Paragraph 1			To extent needed for IRSC Scope.
3.1	Summarize findings	Section 5, Paragraph 1			Covered by IRSC, expert group, and SHED reports
3.2	Consider and categorize findings into major cause categories:	Section 5, Paragraph 1			Action has been performed by the IRSC committee. BAH causes related, but different conclusions and format.
3.2.1	Equipment/material problem				Sample not suitable for intended use.
3.2.2	Procedure problem				Documented
3.2.3	Personnel error				Documented
3.2.4	Design problem				Documented
3.2.5	Training deficiency				Documented
3.2.6	Management problem				Absence of Mgmt accountability.
3.2.7	External phenomena				Safety Culture LTA.
3.3	Analyze and determine the events and causal factor chain:	Section 5.1, Paragraph 1			As far as it went. Only a general requirement covers this in the NIST Safety Operational System (SOS).
3.3.1	Identify the problem	Section 5.1, Paragraph 1			As far as it went. Many other ramifications than were considered.
3.3.2	Determine severity of consequences	Section 5.1, Paragraph 1		X	No determination in evidence. As far as it went. No mention of credibility of past end product results if arrived at using similar LTA methods, no work plans, poor records, etc.

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Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
3.3.3	Possibility of problem recurrence	Section 5.1, Paragraph 1			Not really addressed.
3.3.4	Determine if occurrence is symptomatic of poor attitude, a safety culture problem, or other widespread program deficiency	Section 5.1, Paragraph 1			Point acknowledged in IRSC Report.
3.3.5	Determine the significance of the problem and base level of assessment effort upon estimation of event significance	Section 5.1, Paragraph 1			Recognized need for external, Formal Root Cause Analysis.
3.3.6	Identify the causes (conditions or actions) immediately preceding and surrounding the problem (the reason the problem occurred)	Section 5.1, Paragraph 1			Covered by IRSC and expert group reports.
3.3.7	Identify the reasons why the causes in the preceding step existed, working back to the root cause	Section 5.1, Paragraph 1			Covered in IRSC report
3.4	Summarize findings, list the causal factors and list corrective actions:	Section 5.1, Paragraph 2			Covered in IRSC report, BAH conclusions and recommendations may differ.
3.5	Summarize findings using worksheet in DOE-NE-STD-1004-92, Appendix B	Section 5.1, Paragraph 2	X		Outside scope of IRSC effort.
3.6	Classify each finding or cause by the cause categories in DOE-NE-STD-1004-92, Appendix A	Section 5.1, Paragraph 2	X		Outside scope of IRSC effort. Not required by NIST SOS.
3.7	Select the one (most) direct cause	Section 5.1, Paragraph 2			Multiple direct causes listed in IRSC report. BAH conclusions may differ

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
3.8	Select the root cause	Section 5.1, Paragraph 2			Single root cause identified in IRSC report. BAH draws different conclusion
3.9	Up to three contributing causes may be selected	Section 5.1, Paragraph 2			Multiple (more than 3) contributing causes referenced in IRSC report. BAH conclusions may differ
3.10	Describe the corrective actions selected to prevent recurrence, including the reasons why they were selected and how they will prevent recurrence	Section 5.1, Paragraph 2		X	Identified general CAs needed, including enhanced Safety Culture, Mgmt accountabilities, work controls, etc. No analysis of how corrective actions will prevent recurrence
3.11	Collect additional information as necessary	Section 5.1, Paragraph 2			Report did not mention Worker 1 was a foreign researcher. Information provided by NIST upon request.
3.12	Enter the occurrence report using ORPS, matching the direct cause, root cause and contributing causes with one of the categories given in DOE-NE-STD-1004-92	Section 5.1, Paragraph 3	X		NIST lies within the US Department of Commerce and not covered by ORPS. The NIST SOS has a general reporting requirement, but a formal data generation, acquisition, analysis, reporting and follow-up system is not specified.
3.13	Root cause analysis methods such as: Change Analysis, Barrier Analysis, Event and Causal Factor Analysis, Management and Oversight Risk Tree Analysis, Human Performance Evaluation and Kepner-Tregoe Problem Solving and Decision Making are selected and applied within the scope for which they were defined	Section 5.2, Paragraph 1	X		No specific requirement for this in NIST SOS. Report called for formal Root Cause Analysis. Report does make use of event and causal factor analysis to limited extent. Report needs to include a human performance evaluation

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
4.0	Identify the corrective action for each cause and ensure the viability of each action:	Section 6, Paragraph 1		X	IRSC report stated generalized CAs and left Management with recommendations for further actions. No such further actions in evidence. No evidence of analysis of viability
4.1	Determine if a corrective action will prevent recurrence	Section 6, Paragraph 1		X	Called for a Formal Root Cause Analysis to develop corrective action recommendations. No analysis of recurrence prevention.
4.2	Determine if a corrective action is feasible	Section 6, Paragraph 1		X	Same as above.
4.3	Determine if a corrective action allows for meeting primary objectives or mission	Section 6, Paragraph 1		X	Did not address effect Incident could have on NIST mission credibility.
4.4	Determine if a corrective action introduces new risks and clearly state any new risks	Section 6, Paragraph 1		X	Specific corrective actions not addressed.
4.5	Determine if the immediate actions taken were appropriate and effective	Section 6, Paragraph 1		X	Briefly mentioned ineffectual first response actions, but didn't address effectiveness of recovery operations.
4.6	Systems approach is used to determine appropriate corrective actions	Section 6, Paragraph 2		X	CAs arrived at intuitively.
4.7	Consider potential impact that corrective actions may have on other aspects of safety	Section 6, Paragraph 2		X	Not addressed; beyond scope of IRSC Investigation.
4.8	Proposed corrective action impact on other facilities and their operations considered (NIST Campuses)	Section 6, Paragraph 2		X	Scope limited to NIST Boulder and indirectly to Gaithersburg,
4.9	Proposed corrective actions compatible with facility commitments and other	Section 6, Paragraph 2		X	Same as above.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
	obligations				
4.10	Persons affected by corrective actions, including management, are involved in the process	Section 6, Paragraph 2	X		Outside of scope of IRSC Investigation.
4.11	Proposed corrective actions are prioritized based on importance	Section 6, Paragraph 2		X	Tasked NIST Management to set priorities. No evidence of prioritization.
4.12	Proposed corrective actions are scheduled	Section 6, Paragraph 2		X	Unknown.
4.13	Proposed corrective actions are entered into a commitment tracking system	Section 6, Paragraph 2		X	Unknown; NIST SOS has only a general requirement for commitment tracking.
4.14	Proposed corrective actions are implemented in a timely manner	Section 6, Paragraph 2		X	Subjective rating largely irrelevant considering huge challenges to be met.
4.15	Corrective action program is based not only on specific causes of an incident, but also on items such as lessons learned from other facilities, appraisals and employee suggestions	Section 6, Paragraph 2		X	
4.16	Management is involved at the appropriate level and willing to take responsibility and allocate adequate resources	Section 6, Paragraph 3		X	Appropriately observed Management was LTA in virtually all areas. No evidence of current management response.
4.17	Further considerations in developing and implementing corrective actions:	Section 6, Paragraph 4		X	No actions taken yet.
4.17.1	Corrective actions address all causes	Section 6, Paragraph 4		X	Specific corrective actions not formulated.

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Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
4.17.2	Detrimental effects of corrective actions	Section 6, Paragraph 4		X	Same as above.
4.17.3	Consequences of implementing corrective actions	Section 6, Paragraph 4		X	Same as above.
4.17.4	Consequences of not implementing corrective actions	Section 6, Paragraph 4		X	Addressed in broad and incomplete terms.
4.17.5	Cost (capital, operating and maintenance) of implementing corrective actions	Section 6, Paragraph 4		X	Corrective actions not yet fully defined.
4.17.6	Training required as part of implementation	Section 6, Paragraph 4		X	Observed Training LTA.
4.17.7	Reasonable time frame for corrective action implementation	Section 6, Paragraph 4		X	Corrective actions not yet fully defined.
4.17.8	Resources required for successful implementation and continuing effectiveness of corrective actions	Section 6, Paragraph 4		X	Corrective actions not yet fully defined.
4.17.9	Impact of the development and implementation of corrective actions on other work groups	Section 6, Paragraph 4		X	Corrective actions not yet fully defined.
4.17.10	Measurability of corrective action implementation	Section 6, Paragraph 4		X	Corrective actions not yet fully defined.
5.1	Electronic reporting to ORPS	Section 7, Paragraph 1	X		Not required to use ORPS or any similar formal system.
5.2	Reports distributed (especially lessons learned) to aid in effectively preventing recurrences	Section 7, Paragraph 1	X		Report results preliminary and incomplete.
5.3	Methods and procedures put in place to identify personnel who have an	Section 7, Paragraph 1	X		Not required by NIST SOS.

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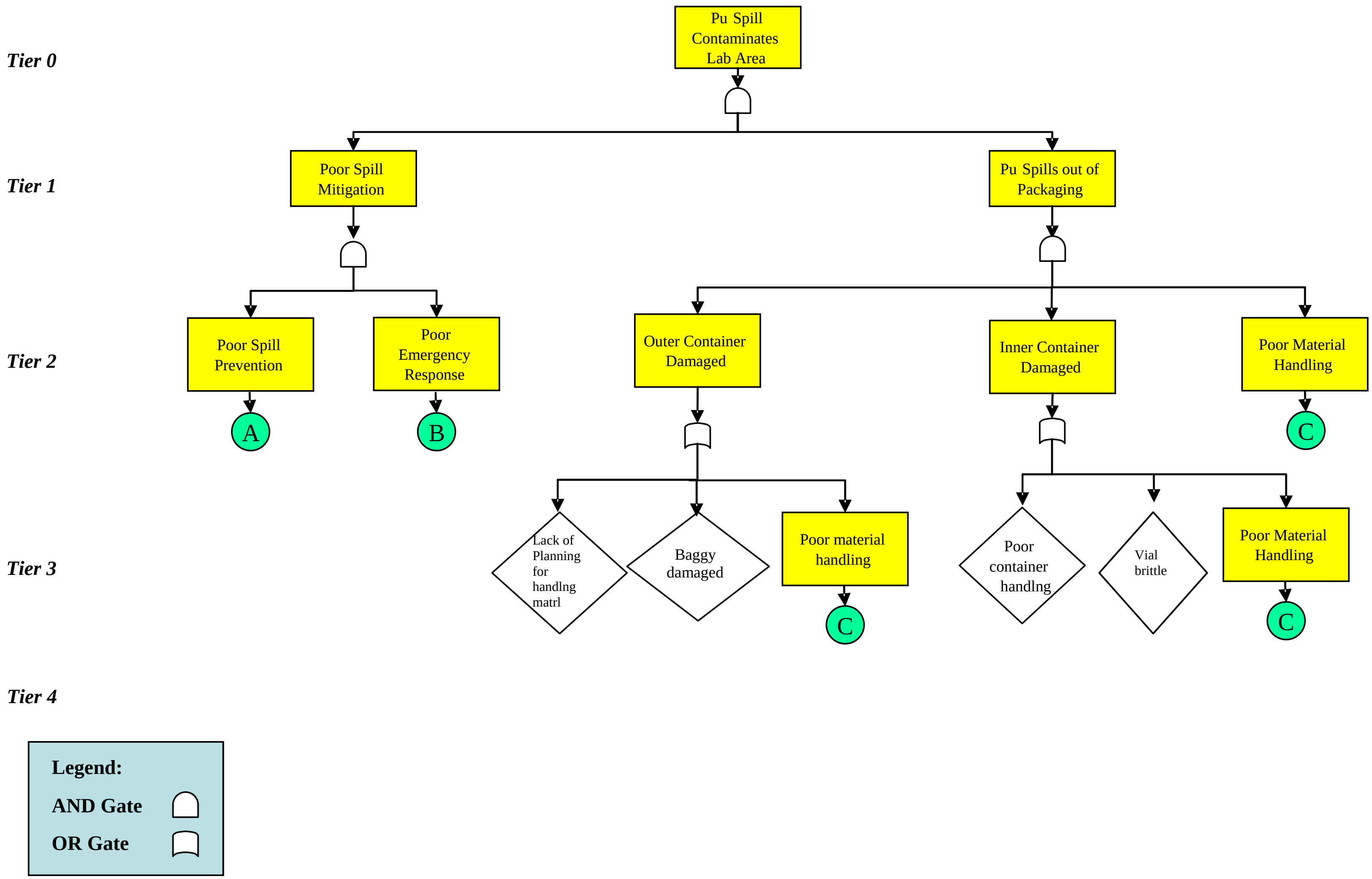
Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
	interest to support essential communication				
5.4	Internal self-appraisal report identifying management and control system defects presented to management for serious occurrences	Section 7, Paragraph 2		X	General requirement in NIST SOS; no evidence.
5.5	Consideration given to sharing details of root cause information with similar facilities where significant or long-standing problems may also exist	Section 7, Paragraph 3		X	Corrective actions not yet fully defined.
6.1	Determine if corrective actions have been effective in resolving problems:	Section 8, Paragraph 1	X		Corrective actions not yet fully defined.
6.2	Corrective actions are tracked to ensure proper implementation and function	Section 8, Paragraph 1	X		Corrective actions not yet fully defined.
6.3	Periodic structured review of corrective action tracking system, normal process and change control system and occurrence tracking system	Section 8, Paragraph 1	X		No requirement of formal ORPS-type system in NIST SOS.
6.4	Recurrence of same or similar events identified and analyzed	Section 8, Paragraph 1	X		Corrective actions not yet fully defined.
6.5	Original occurrence re-evaluated if an occurrence recurs.	Section 8, Paragraph 1	X		Corrective actions not yet fully defined.
6.6	New occurrence investigated using change analysis	Section 8, Paragraph 1	X		Corrective actions not yet fully defined.

Item #	Line of Inquiry	DOE Standard Reference	Not Applicable	Gap	Comments
6.7	Process change control system evaluated to determine what improvements are needed to keep up with changing conditions	Section 8, Paragraph 1	X		No such requirement in NIST SOS.
6.8	ORPS database reviewed to identify good practices and lessons learned from other facilities	Section 8, Paragraph 1	X		No such requirement in NIST SOS.
6.9	Prompt corrective actions taken to reverse deteriorating conditions or to apply lessons learned	Section 8, Paragraph 1	X		No such requirement in NIST SOS.

APPENDIX C: PLUTONIUM SPILL FAULT TREE (1/7)



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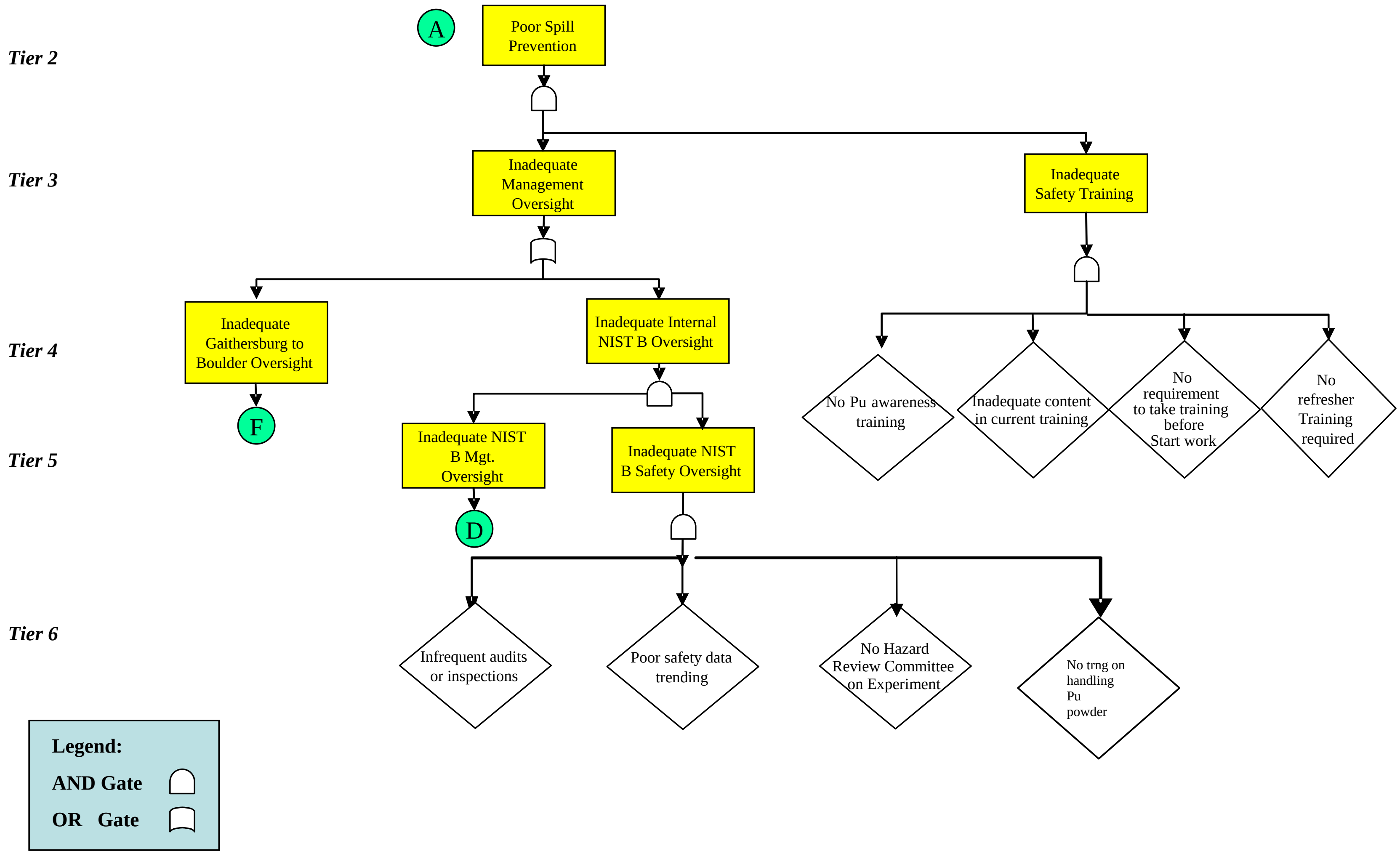
Plutonium Spill Fault Tree (2/7)



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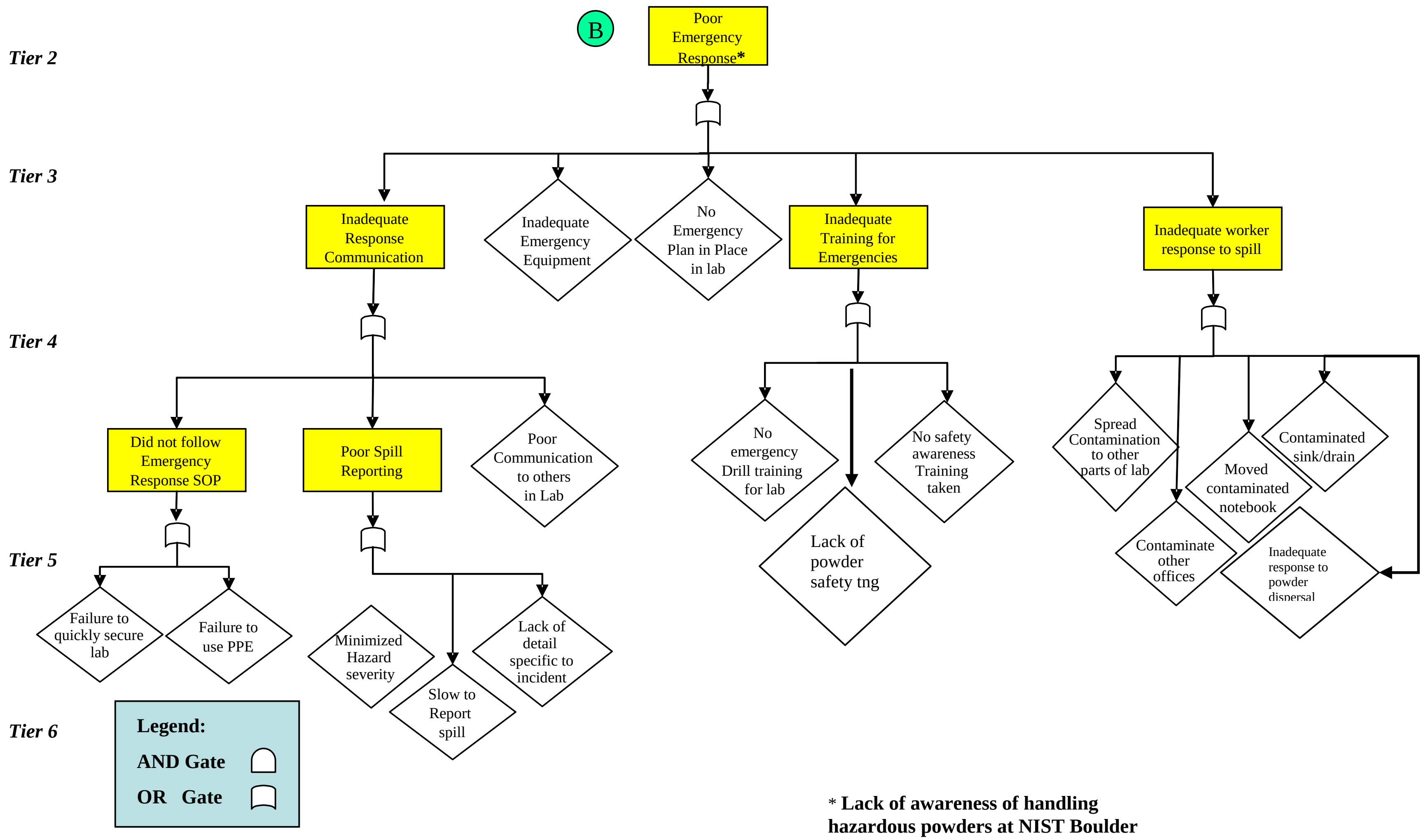
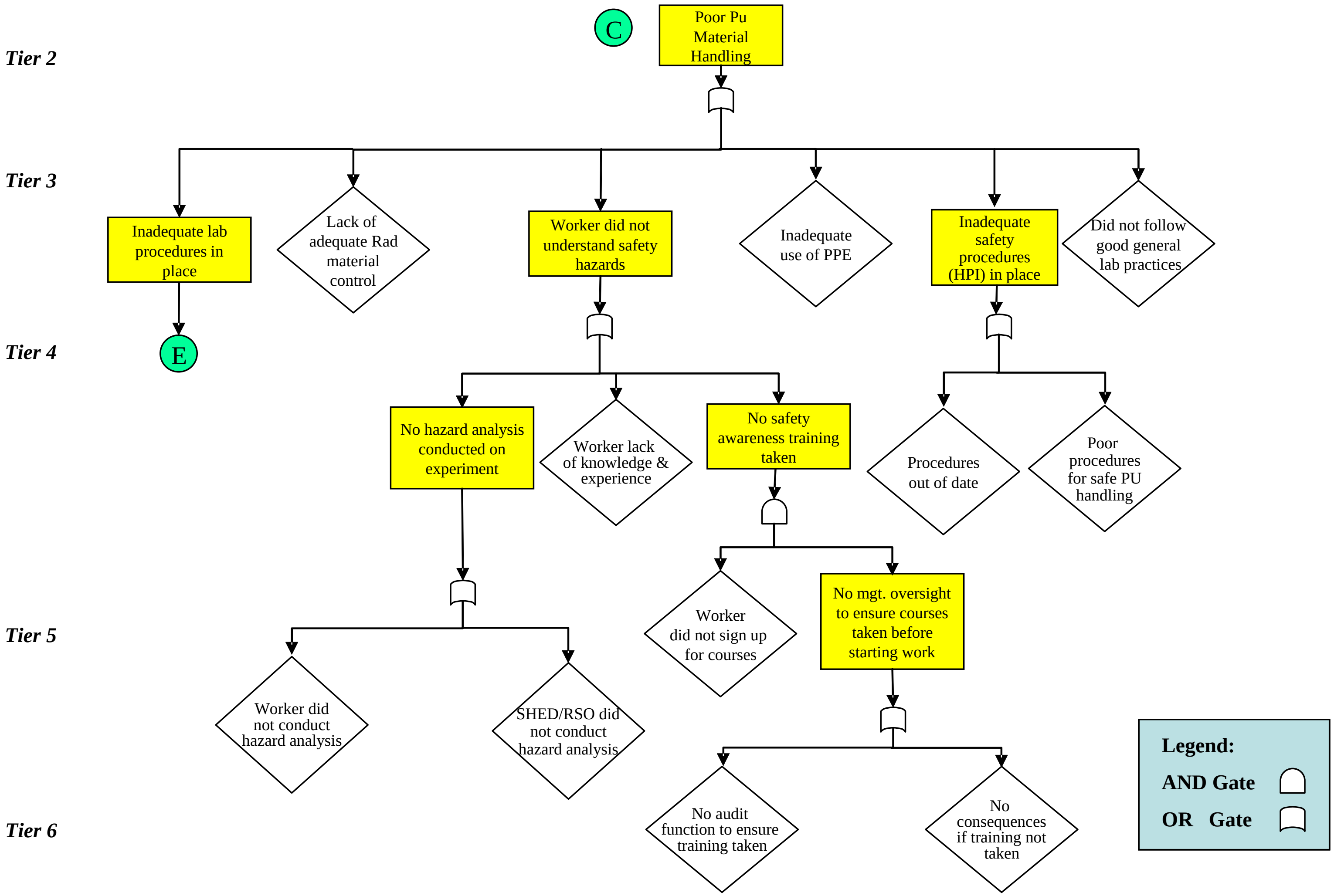
Lack

Plutonium Spill Fault Tree (3/7)

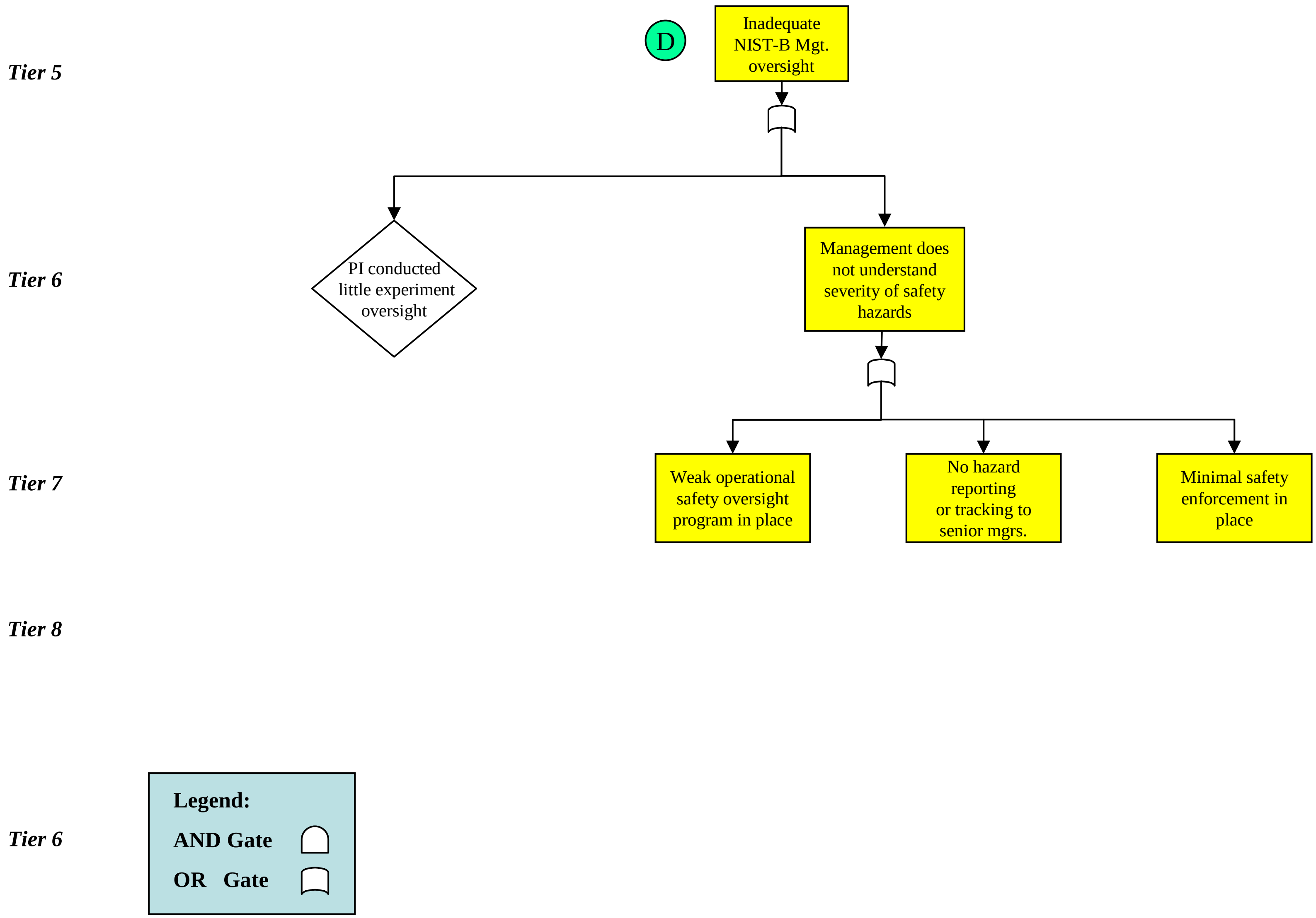


*** Lack of awareness of handling hazardous powders at NIST Boulder**

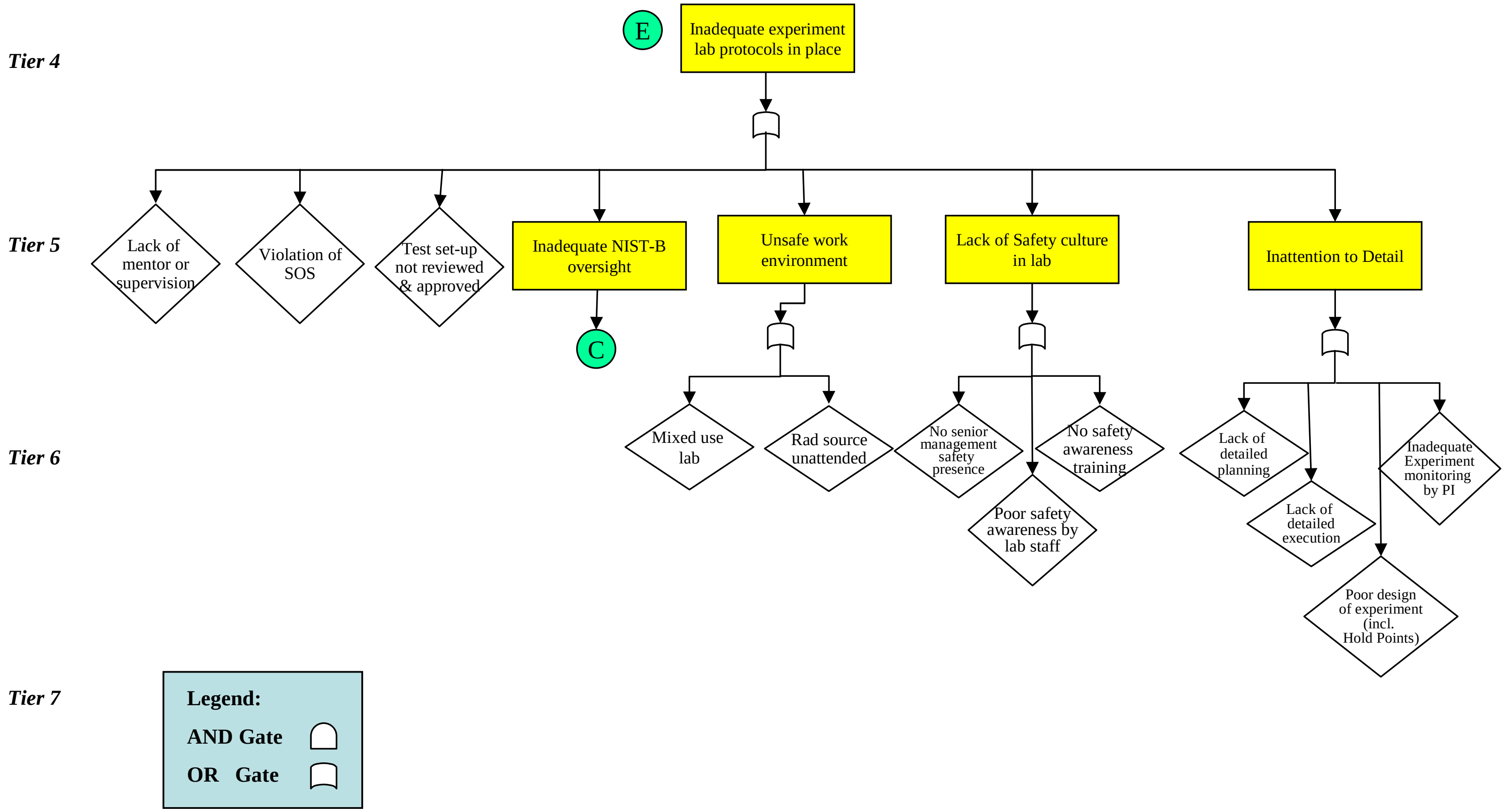
Plutonium Spill Fault Tree (4/7)
Boulder Facility



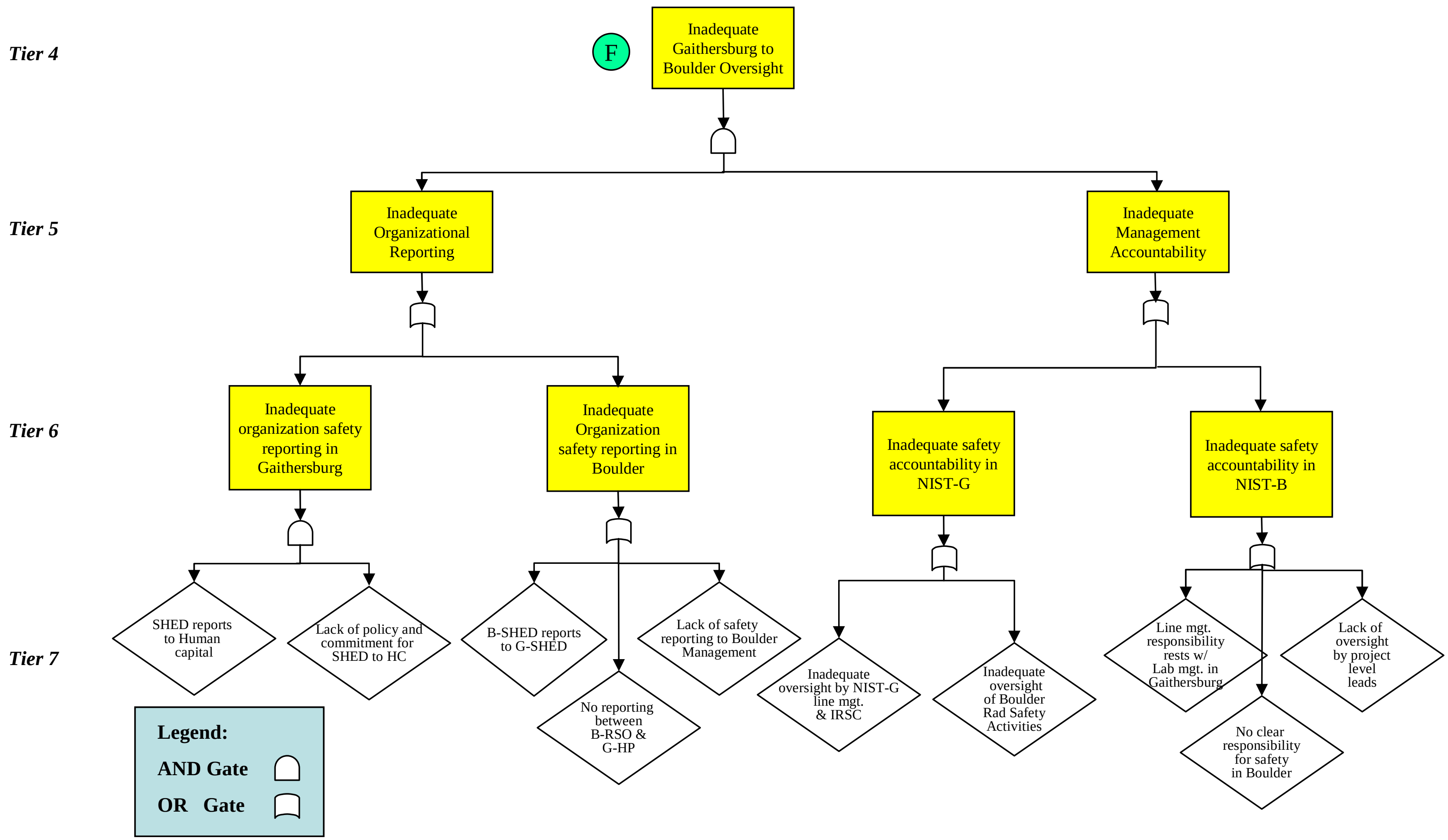
Plutonium Spill Fault Tree (5/7)



Plutonium Spill Fault Tree (6/7)



Plutonium Spill Fault Tree (7/7)



APPENDIX D: ATTACHMENT D: REPORT COMPARISON MATRIX

IRSC Report Finding	BAH Report	Reference	DOE STD 1004-92 Cause Code
"Failure in the existing NIST safety management system as it was applied to the detector project being carried out by the researchers in Boulder." (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight	Fault trees 5 and 7	6A,6B, 6C, 6D,6E
Deficiency in ensuring that appropriate radiation safety requirements and processes are established (Root cause - page 31)	Lack of management commitment and accountability, inadequate operational safety management system	Fault trees 4 and 5	2B,6A, 6B,6D
Deficiency in ensuring that researchers and line management are aware of radiation safety requirements and processes (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight	Fault trees 4, 6 and 7	6C,6E
Deficiency in ensuring that researchers comply with radiation safety requirements and processes (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight	Fault trees 4 and 6	6A,6C,6E
Deficiency in ensuring that researchers and supervisors have adequate training to perform their assigned work and conversely, not assigning work to persons untrained and unqualified to perform that work (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight, poor safety training	Fault trees 4, 5 and 7	5A, 5C, 5E, 6A, 6C, 6D
Deficiency in ensuring that researchers and first-level supervisors adequately understand the hazards in their workplace and take appropriate action to control them (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight, poor organizational safety culture, inadequate hazard analysis	Fault trees 2 and 4	3A, 3D, 4B, 6A, 6B, 6C

IRSC Report Finding	BAH Report	Reference	DOE STD 1004-92 Cause Code
Deficiency in applying effective assessment and review processes to identify hazards and establish appropriate controls (Root cause - page 31)	Lack of management commitment and accountability, inadequate management oversight, poor organizational safety culture, inadequate hazard analysis	Fault trees 2 and 5	2A,6B, 6C, 6E
Deficiency in providing adequate resources and facilities to ensure the safe conduct of operations (Root cause - page 32)	Lack of management commitment and accountability, inadequate management oversight, poor organizational safety culture	Fault tree 6	3A, 4A,6A,6B,6C,6D,6E
Deficiency in appropriately supervising work (Root cause - page 32)	Lack of management commitment and accountability, inadequate management oversight	Fault trees 4, 5 and 7	6C
Deficiencies in monitoring and auditing activities and programs for safety effectiveness. (Root cause, page 32)	Lack of management commitment and accountability, inadequate management oversight	Fault trees 2, 4 and 5	6A, 6C,6E
Most probable direct cause of the spill event is striking the glass, which had been removed from all other secondary protection and containment, against a fixed obstacle during the experiment (Direct cause - page 32)	Inadequate management oversight, poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault tree 1	1A, 2B, 3A, 3B,3E,4A, 4B,6A,6B,6D,6E
Most probable direct cause of the larger scale of the contamination event is the direct handling to the broken source bottle by both the researcher and his supervisor… (Direct cause - page 32)	Inadequate management oversight, poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault tree 3	5A, 5B, 6A, 6B 6C, 6D, 6E
The most probable direct cause of the spread of contamination outside the laboratory area is the multiple, uncontrolled entries into and exits from the contaminated laboratory after the spill (Direct cause - page 32)	Inadequate management oversight, poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault tree 3	2A, 3A, 3C,3D, 5A, 6A, 6B, 6C,6E
The most probable direct cause of the release of plutonium into the sanitary sewer was Worker 1 washing his hands in the sink after they were contaminated (Direct cause - page 32)	Inadequate management oversight, poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault tree 3	2A,3A,3E,5A,6C

IRSC Report Finding	BAH Report	Reference	DOE STD 1004-92 Cause Code
The failure to properly recognize the significant hazards associated with a powdered plutonium source … had devastating consequences for subsequent events. (Contributing cause - page 32)	Inadequate hazard analysis	Fault trees 2 and 4	2A, 6B, 6E
The participants failed to understand that the work represented a significant risk change from the previous radioactive source work in Boulder. (Contributing cause - page 32)	Poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault trees 2 and 4	2A,2B,3B, 5A,6A,6B
The incident was characterized by widespread failures to apply established procedures, controls, methods, and training requirements needed to safely work with this class of radioactive material. (Contributing cause - page 33)	Inadequate management oversight, inadequate operational safety management system, poor organizational safety culture, inadequate hazard analysis, poor safety training	Fault trees 2, 3 and 4	3B, 5A,5B,6A, 6B, 6C,6D
The IRSC approved changes to the Boulder license that was non-specific for limited quantities of SNM but failed to ensure suitable controls….. (Contributing cause - page 33)	Inadequate management oversight, inadequate operational safety management system, poor organizational safety culture, inadequate hazard analysis	Fault tree 4	3B,3C,6A,6B,6C
Many contributing events were characterized by a cavalier attitude regarding the safety consequences of work … (Contributing cause - page 33)	Poor organization safety culture	Fault trees 4 and 6	6A, 6C, 6E
Key participants, including the B-RSO and the PI, did not appear to have understood their roles, responsibilities, authorities, or accountability under the NIST radiation safety program or NRC license….. (Contributing cause - page 33)	Inadequate management oversight, inadequate operational safety management system	Fault trees 5 and 7	2B,5A,6A, 6B, 6C, 6E
The sequence of events covered by this review is notable for the complete absence of any role by the EEEL program line managers.	Lack of management commitment and accountability	Fault tree 7	6A, 6B, 6C

APPENDIX D - CAUSE CODES FROM DOE STANDARD

1. Equipment/Material Problem

1A = Defective or failed part
lB = Defective or failed material
lC = Defective weld, braze, or soldered joint
ID = Error by manufacturer in shipping or marking
lE = Electrical or instrument noise
lF = Contamination

2. Procedure Problem

2A = Defective or inadequate procedure 2B = Lack of procedure

3. Personnel Error

3A = Inadequate work environment
3B = Inattention to detail
3C = Violation of requirement or procedure
3D = Verbal communication problem
3E = Other human error

4. Design Problem

4A = Inadequate man-machine interface
4B = Inadequate or defective design
4C = Error in equipment or material selection
4D = Drawing, specification, or data errors

5. Training Deficiency

5A = No training provided
5B = Insufficient practice or hands-on experience
5C = Inadequate content
5D = Insufficient refresher training
5E = Inadequate presentation or materials

6. Management Problem

6A = Inadequate administrative control
6B = Work organization/planning deficiency
6C = Inadequate supervision
6D = Improper resource allocation
6E = Policy not adequately defined, disseminated, or enforced
6F = Other management problem

7. External Phenomenon

7A = Weather or ambient condition
7B = Power failure or transient
7C = External fire or explosion
7D = Theft, tampering, sabotage, or vandalism

APPENDIX E: RECOMMENDATIONS

The recommendations included in this report are provided for NIST consideration, and ***were not required*** in the scope of the contract with Booz Allen Hamilton. Booz Allen Hamilton was only contracted to provide a root cause analysis based on the data and information provided by NIST, and the root cause analysis was not required to be a complete, independent, investigative analysis. If an independent root cause analysis investigation was conducted, recommendations for addressing the root cause findings and improving the program to preclude recurrence would be an inherent part of the report. These recommendations are ***optional*** and provide some potential considerations and actions to address the findings based on our extensive experience in conducting accident investigations and root cause analyses.

Based on the NIST IRSC report, the NRC Confirmatory Action Letter dated July 02, 2008, this report, and the Independent Oversight Special Review of Safety at the NIST Boulder Laboratories report dated August 2008, NIST clearly has a directive to make major policy and organizational changes to effect a safety culture and to institutionalize it through a focused institutional broad based effort and consider organizational alignments to ensure the execution of new policies and actions. The following recommendations may be considered to support effective corrective actions. These recommendations are not prioritized or weighted:

1. Consider conducting assessments of all laboratories for safety practices across the NIST complex by an independent organization to determine if there are other potential safety issues that could emerge, and institute similar corrective actions to those considered for Boulder.
2. Senior and Line management commitment and renewed accountability enforcement is needed to achieve Safety Performance excellence in an enhanced Safety Culture working environment at the Boulder Lab. Additionally, operational enhancements are needed to extend SOS principles and goals into action and implementation. Consider developing new policies issued by the Director of NIST requiring all managers to commit to a safety culture and incorporating objectives into personnel performance criteria. Implement a process that holds managers and supervisors accountable for visibly being involved, setting the proper example, and leading positive change for safety and health. Ensure that organizational alignments reflect added emphasis on safety.
3. Evaluate and rebuild any incentives & disciplinary systems for safety and health as necessary.
4. Commission immediate development of Laboratory Operations and Laboratory Safety Operations programs to implement provisions of the SOS and RS Administrative Manual sub-chapters tailored to Boulder application. Establish clear ownership and accountability for the programmatic development and implementation within NIST, augmented by subject matter expertise support external to NIST. (The preliminary set of HP instructions for Boulder provides a good base for development of the programs).
5. Strengthen work planning, approval and oversight accountabilities for the line, staff and safety workers and managers in an integrated process to optimize use of resources.
6. Develop and implement a set of Lab Performance Standards to promote achievement of SOS and RS values and objectives and foster personal accountabilities for them.

7. Define safety responsibilities for all levels of the organization, e.g., safety is a line management function.
8. As an adjunct activity to the above listed activities, determine an optimum organizational relationship between Gaithersburg and Boulder that aligns technical, financial and safety accountabilities equitably. For example, safety is not addressed on the NIST website as an organizational priority, nor is the safety function listed on the organizational chart. Both omissions indicate a lack of visible priority for the safety function. Consider making organizational changes to better align environment, safety, and health issues reporting to a senior management level.
9. Ensure that the NIST financial system includes appropriate overhead for adequate safety activities that addresses the needs of research with the tailored safety requirements while achieving cost-effective operations.
10. Develop and implement a training (including formal mentoring) program to adequately prepare all managers, researchers and other personnel to achieve performance excellence before being authorized to do assigned work. Incorporate refresher training in staff activities to continually reinforce safety awareness and accountability.
11. Institute a hazard identification, risk evaluation, mitigation planning and acceptance procedure into the work planning process to assure line and functional manager awareness and approval. Each design of experiment should result in a work plan of appropriate rigor that includes a section on hazard identification and risk management, and emergency response with commensurate responsibility assignments. Work plans should also include a section defining success factors and performance metrics to assess their achievement. (Perhaps one of the more simple and effective risk management techniques is to require progressively higher one-over-one approval for work authorization based on the results of hazard and risk evaluation during the work planning process).
12. Assign safety responsibilities for laboratory space management and operational activities for every campus, including chain-of-custody accountability for hazardous, toxic and radioactive materials.
13. Incorporate the necessary discipline into the procurement process to assure line and functional manager awareness and approval of acquisition of all toxic, hazardous and radioactive sources in timely response to project needs.
14. Develop, define, and implement a performance measurement and monitoring system to assess achievement of work and safety objectives for projects and laboratory operations. Ensure that effective Key Performance Indicators (KPIs) are established, measured and reported, that a detailed trend analysis system is established, and corrective actions are tied to the Performance Management System.
15. Develop an effective nonconformance and corrective action system that analyzes root causes, and develops effective corrective actions based on the root causes.
16. Institute a lessons learned program to mitigate consequences of potential occurrences through awareness building.