U.S. Department of Energy
National Nuclear Security Administration

Type B Accident Investigation

Acid Vapor Inhalation on June 7, 2005, in Technical Area 48, Building RC-1, Room 402 at Los Alamos National Laboratory

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RELEASE AUTHORIZATION

On August 15, 2005, I appointed a Type B Accident Investigation Board (the Board) to investigate the June 7, 2005, Acid Vapor Inhalation Incident that occurred at Tech Area 48, building RC-1, Room 402, at Los Alamos National Laboratory. The Board's responsibilities have been completed with respect to this investigation. The analysis and the identification of the contributing causes, the root cause, and the Judgments of Need resulting from this investigation were performed in accordance with DOE Order 225.1A, *Accident Investigations.*

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

Edwin L. Wilmot
Los Alamos Site Office Manager
U.S. Department of Energy

9/27/05
Date

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ACRONYMS

CAP	Corrective Action Plan
C-INC	LANL Chemistry Division Isotope and Nuclear Chemistry Group
COR	Contracting Officer Representative
C-SIC	LANL Chemistry Division Actinide Catalysis and Separations Group
DOE	Department of Energy
ES&H	Environment, Safety, and Health
FR	DOE Facility Representative
GET	LANL General Employment Training
HSR-2	LANL Occupational Medicine Group
HSR-5	LANL Institutional Industrial Hygiene and Safety Group
HSR-8	LANL Operation and Facility [IH&S] Support Group
IDLH	Immediately Dangerous to Life and Health
IMP	Implementation Procedure
ISM	Integrated Safety Management
ISMS	Integrated Safety Management System
IWD	Integrated Work Document
IWM	Integrated Work Management
JHA	Job Hazards Analysis
JON	Judgment of Need
LANL	Los Alamos National Laboratory
LC_{50}	Lethal Concentration 50 Percent
LIR	Laboratory Implementation Requirement
MSDS	Material Safety Data Sheet
NIOSH	National Institute for Occupational Safety and Health
ORPS	DOE Occurrence Reporting and Processing System
PEL	Permissible Exposure Limit
PIC	Person-In-Charge
PNOV	Preliminary Notice of Violation

RC	Radiochemistry
RDL	Responsible Division Leader
RLM	Responsible Line Manager
SME	Subject Matter Expert
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value

EXECUTIVE SUMMARY

The Accident

During the afternoon of June 7, 2005, two postdoctoral (postdoc) employees working at the Los Alamos National Laboratory (LANL) inhaled acid vapors generated by the use of aqua regia (a mixture of hydrochloric and nitric acids) to clean glassware on a laboratory benchtop. The acid vapor exposure caused a delayed lung injury to one of the postdocs that resulted in the postdoc being hospitalized for six days. Upon return to work on August 3, 2005, the postdoc notified the LANL Medical Director who determined the hospitalization was related to the acid vapor exposure.

The Laboratory notified the Los Alamos Site Office (LASO) of the incident on August 4, 2005. On August 15, 2005, the Los Alamos Site Office Manager appointed a Type B Accident Investigation Board (the Board) to investigate the accident in accordance with DOE Order 225.1A, *Accident Investigations*.

Analysis and Results

The events leading up to the accident showed C Division had not fully implemented LANL Integrated Work Management (IWM) processes. Although a recent C Division Management Self-Assessment identified implementation of IWM processes as an issue, a planned assessment of IWM implementation had not been conducted. Managers, supervisors, and staff did not fully understand the hazards associated with the use of aqua regia. The events following the accident indicate that LANL did not have an adequate program to ensure near misses are reported. The Board identified deficiencies in the line management organizations of NNSA/LASO, LANL and C Division.

C Division considered the use of aqua regia in a hood to be a routine task within the expertise of technical staff members and postdocs. Work with aqua regia in C Division was normally conducted in a functional laboratory hood. Due to a ventilation fan failure, an alternate work location was being authorized. For the June 7, 2005, cleaning of laboratory glassware with aqua regia, the Board identified the following key deficiencies:

- The document originally authorizing the work did not identify significant hazards associated with the use of aqua regia, leading to an improper hazard grading of moderate instead of high hazard.

- Changes made to the work authorization document did not list the specific task of using aqua regia to clean laboratory glassware and did not fully identify significant hazards associated with other authorized analytical tasks.

- A mandatory pre-job briefing was not conducted in the manner specified by LANL IWM processes leading to a lack of understanding as to where the work was to be conducted and what controls were required.

- Workers involved in the accident had not completed training required for their roles and responsibilities in LANL IWM processes associated with planning their use of aqua regia.

- The workers involved did not report the accident immediately after the event, even though they both suffered temporary health effects from the initial exposure. The supervisor failed to report the accident after it was reported by those directly exposed. A report of the incident to a LANL safety and health professional in another directorate also did not result in notification to management of the event.

The accident resulted from deficiencies in implementation of LANL work control planning and implementation processes by LANL Chemistry Division (C Division). In addition, the failure to report what originally should have been perceived as a near miss incident deprived LANL of the opportunity to take steps to minimize the severity of the injury. C Division has had two similar accidents in the last two years that warranted investigations by LANL accident investigation teams.

Conclusion

The Board concludes that this accident was preventable. The direct cause of this accident was making and using aqua regia outside a functional laboratory hood resulting in workers inhaling acid vapors and other toxic constituents. Had this work been performed in a functional laboratory hood, the accident would have been prevented.

The Board determined that the events that occurred on June 7, 2005, violated all the Integrated Safety Management (ISM) Core Functions and several Guiding Principles. For the full discussion of the Board's Conclusions and Judgments of Need, see Section 6 of this report.

1 BACKGROUND

1.1 Technical Area 48, Building RC-1, Room 402

RC-1 is a research and development (R&D) facility constructed in various phases from 1955 through the 1980s. Current R&D operations include radionuclide transport research, environmental remediation research, nuclear and radiochemistry, high-level beta and gamma chemistry, actinide transuranic (TRU) chemistry, data analysis, inorganic chemistry, low-level measurement, and sample counting (alpha, beta, and gamma).

RC-1 is a 103,000 square-foot structure, which includes a basement and a penthouse. Construction includes a concrete foundation and supporting steel columns and exterior walls constructed of various materials including reinforced masonry with stucco and metal siding exterior finish. The roof consists of a flat, built-up roofing system. A majority of the work is conducted in laboratories on the main floor. The basement houses ventilation ductwork, several storage areas, and several laboratories. Air supply fans and equipment for heating and cooling are located in the penthouse. On the flat roof are various vent pipes, vents, and exhaust stacks through which room air, hoods, and gloveboxes are vented.

The facility is divided into an office wing, light chemistry laboratory areas for performing low-level radiochemistry, a hot cell complex utilized for production of medical isotopes, an alpha wing used for chemical research of high alpha-emitting radioactive and toxic materials, a counting room used for qualitative and quantitative analysis of radiochemical samples, an Actinide Research Facility utilized for development of dissolution and separation techniques, a secure Data Wing, a Classified Media Library, and a vault containing historical weapons data.

TA-48, Building-1 (RC-1) was re-categorized from a Nuclear Hazard Category 3 facility to a Radiological Facility in June 2003. The re-categorization was authorized by NNSA's memorandum *Categorization of Technical Area-48, Radiochemistry Facility-1 to Non-Nuclear Hazard Category C*, dated November 15, 2003. The *Facility Safety Plan for TA-48, Building 1 FSP-C-OPS-4801.7*, dated December 22, 2004, identified TA-48, Building 1 as a Category C, radiological, low-hazard facility. The Facility Safety Plan identified all hazards (physical, radiation, electrical chemical, environmental and transportation) as "low."

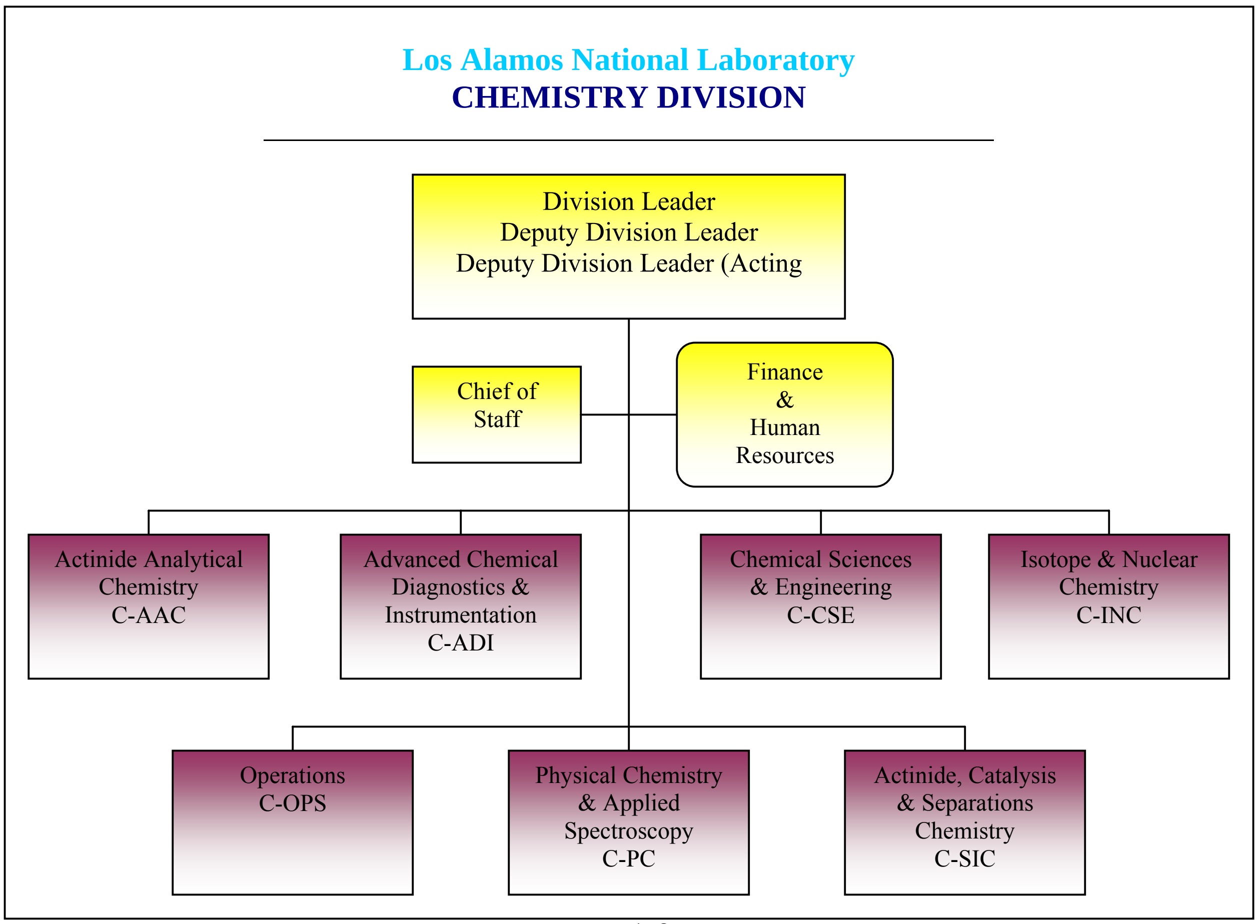
The *LANL Nuclear Facility List, PS-SBO 401*, was revised in February 2004 to reflect the re-categorization of RC-1. However, a LANL managed list, *LANL Radiological Facilities List PS-OAB 403*, last revised in 2002 and approved on January 12, 2003, was not revised to include RC-1 as a radiological facility. *List PS-OPS-403* was sent to LASO for information in September of 2002. After reviewing the list, LASO required LANL to review all of the Radioactive Material Inventory tables due to errors identified by LASO. The Board could not identify a current listing of radiological facilities. LANL stated the Radiological Facilities List was being updated and was not updated annually as required in Laboratory procedures.

1.2 NNSA Los Alamos Site Office

NNSA had established eight site offices to oversee environment, safety, and health (ES&H), security and programmatic activity at assigned sites. The Los Alamos Site Office (LASO) was responsible to oversee LANL and was staffed by approximately 110 employees. The LASO groups that performed ES&H oversight included the Safety and Health Staff, and Facility Operations. In April 2005 there were approximately 12 personnel assigned to the Facility Representative Team. There were 6 personnel assigned to the Safety and Health Staff, which included a senior safety advisor, an industrial hygienist, an occupational safety manager, a fire protection engineer, an emergency manager, and a health physicist.

1.3 LANL Chemistry Division

The LANL Chemistry Division (C Division) consists of the division office, seven technical groups, an operations group, and several teams focused on administration, business, human resources, and communications. Each group name gives an indication of the types of activities being pursued within the group. Many of the research and development projects in the division span several groups and/or divisions, and a number of them involve partnerships with academia, industry, or both.



These offices focus on nuclear weapons, threat reduction, science, applied energy, and environment. They serve as the interface with program elements of the Department of Energy and other federal agencies such as the Department of Defense, the National Institutes of Health, the National Science Foundation, and the Department of Agriculture.

Including technical staff members, technicians, support personnel, students, and postdoctoral researchers (postdocs), there are approximately 450 people in the division. Postdoctoral and student employees account for roughly 20% of the C Division's work force and come from colleges and universities around the country and the world.

In order to be considered for a LANL postdoctoral appointment, candidates must be nominated and sponsored by a member of the Laboratory's technical staff. To identify a potential sponsor, candidates can review the technical divisions and the scientific subject areas of the Laboratory. In addition, candidates can identify potential sponsors at national and international conferences and workshops, by networking with colleagues, or by reading journal publications. Hiring officials look over postdoctoral resumes and contact the postdoctoral candidate directly if the candidate is a good match for their needs. For all postdoctoral appointments the candidate must be within 5 years of completion of PhD when being proposed for review by the committee, or will have completed all PhD requirements by commencement of the appointment. Selection is based on Laboratory-wide competition and is determined by the candidate's academic qualifications and research excellence.

Postdoctoral fellows are assigned mentors by their C Division Group. Mentors are intended to be role models for professionalism and work ethics and are expected to demonstrate constant attention to safety and security. Mentors work with Group Training Coordinators to develop training plans for postdocs and to make arrangements to have on-line courses proctored. The Chemistry Division expects mentors to help postdocs learn in a safe and professional work environment and to establish a framework of what is expected in the workplace. Mentors are expected to meet with their postdocs daily to provide real time feedback on job performance. Mentors may or may not be considered "supervisors" in the usual sense of the term because of the academic atmosphere at LANL. Mentors and postdocs that the Board interviewed typically referred to each other as "colleagues."

Over the years, many of C Division's postdoctoral fellows have joined the Laboratory as technical staff members. Others have gone on to academic, research, national laboratory, or industrial appointments. Facilities located throughout the 43 square miles of the Laboratory support the C Division's research, development, and testing activities. C Division also maintains a suite of modern research equipment that enables staff to address cutting edge scientific problems. C Division has a long history of successfully tackling difficult problems in support of the Laboratory's evolving missions.

Actinide Catalysis and Separations Chemistry (C-SIC), a group within C Division, is an inorganic chemistry research group that integrates actinide/radioisotope chemistry, inorganic and organometallic synthesis, structural analysis, catalysis, spectroscopy, and surface science capabilities. C-SIC focuses on scientific innovation and technical solutions to problems in defense, threat reduction, energy, and the environment.

Postdocs 1 and 2 (PD1 and PD2) worked in C-SIC and were both mentored by Mentor 1 (M1). PD1 had worked in C-SIC since March 2004. PD2 had worked in C-SIC since July 2004. M1 became a C Division postdoc in July 1999 and had been a Technical Staff Member since July 2002. All three had doctoral degrees in chemistry and had previously used aqua regia to clean laboratory glassware.

1.4 Scope and Methodology

The Accident Investigation Board (Board) was appointed on August 15, 2005. The scope of the Board's investigation was to identify all relevant facts; analyze the facts to determine the direct, contributing, and root causes of the accident; develop conclusions; and determine Judgments of Need (JONs). (See Figure 1-2 for an explanation of accident investigation terminology). The investigation was performed in accordance with DOE Order 225.1A, *Accident Investigations,* using the following methodology:

- The accident scene was inspected, physical evidence was collected, and photographs were taken of the scene.

- Facts relevant to the accident were gathered through interviews, reviews of documentation, and examination of the physical evidence.

- The facts were analyzed to identify the causal factors using event and causal factors analysis, barrier analysis, change analysis, and root cause analysis.

- Conclusions and JONs were developed to guide the development of corrective actions that, if implemented, should prevent recurrence of similar accidents.

Figure 1-2 Accident Investigation Terminology

A causal factor is an event or condition in the accident sequence that contributes to the unwanted result. There are three types of causal factors: direct cause(s), which is the immediate event(s) or condition(s) that caused the accident; root cause(s), which is the casual factor that, if corrected, would prevent recurrence of the accident; and the contributing casual factors, which are the causal factors that collectively with the other causes increase the likelihood of an accident but which did not cause the accident.

Event and causal factors analysis includes charting, which depicts the logical sequence of events and conditions (causal factors that allowed the accident to occur), and the use of deductive reasoning to determine the events or conditions that contributed to the accident.

Barrier analysis reviews the hazards, the targets (people or objects) of the hazards, and the controls or barriers that management systems put in place to separate the hazard from the target. Barriers may be physical or administrative.

Change analysis is a systematic approach that examines planned or unplanned changes in a system that caused the undesirable results related to the accident

2 ACCIDENT DESCRIPTION AND CHRONOLOGY OF EVENT

2.1 Accident Description

During the afternoon of June 7, 2005, PD1 and PD2 began cleaning fritted glass Büchner funnels (frits) on the bench top in Room 402 of Building RC-1 in Technical Area (TA) 48 at Los Alamos National Laboratory. The hoods in Room 402 were sealed shut because of a non-operational ventilation fan. These frits were to be cleaned with aqua regia (a mixture of nitric and hydrochloric acids) that was made immediately prior to use.

PD1 poured concentrated nitric acid into a beaker then added concentrated hydrochloric acid until aqua regia formed. PD1 described becoming sick because of the acid vapors. PD1 backed away from the beaker and PD2 stepped up and poured the aqua regia into a beaker containing the frits. When PD2 realized that the acid vapor was too intense, the aqua regia was flushed with water down the drain in Room 402.

PD1 and PD2 left Room 402 and walked to their offices in Building 149. PD2 reported being short of breath during the walk. PD1 and PD2 worked in their respective offices for about 30 minutes. PD1 wanted to return to Room 402 and work in the dry box and told PD2. (A dry box is a glove box ventilated with a dry inert gas, in this case nitrogen, in order to provide an anhydrous, anaerobic atmosphere.) PD1 and PD2 talked for another 15 minutes and returned to Room 402. PD2 stated that the acid vapor had gone away. PD1 and PD2 worked in the dry box.

About the time of the accident, M1 was participating in a quality assurance (QA) review outside the laboratory area. At about 4:00 pm, M1 and the QA reviewer (QAR) went to Room 402 and the QAR expressed concern about smelling solvent odors. M1 told QAR that an industrial hygienist deployed to C Division (IH1) would sample the air in Room 402. The QAR insisted that a different C Division industrial hygienist (IH2) be involved with the sampling.

Around 4:30 pm, M1 met PD1 and PD2 at Room 402. PD2 informed M1 that they had tried to clean frits on the benchtop in Room 402, but had to pour the aqua regia down the sink because of the acid vapor. PD1 and PD2 did not report the accident immediately after the event, nor did they seek medical attention at HSR-2 even though they both suffered temporary respiratory effects from the initial exposure. M1 did not report the accident after it was reported to M1 by PD1 and PD2.

On the evening of June 7, 2005, PD1 informed their spouse of the aqua regia accident. The next day, the spouse mentioned the accident to an industrial hygienist (IH3). IH3 attempted to inform IH2, but was unsuccessful. IH3 went on travel the next day and did not immediately attempt to follow up with IH2.

On June 8, 2005, IH1 and IH2 both monitored the air in or just outside Room 402. Since the QAR reviewer had expressed concern about solvent odors, IH1 and IH2 both used photoionization detectors (PIDs) capable of detecting volatile organic compounds (VOCs) in the parts per billion range. Neither IH detected VOCs at levels of concern. IH2 used a PID again on June 10, 2005 to sample the air in Room 402 and did not detect VOCs at levels of concern. IH1 and IH2 did not discuss potential exposures in Room 402 with M1, PD1, or PD2.

PD1 traveled to Newport, Rhode Island on July 16, 2005 to present a poster at a conference. On July 21, 2005, PD1 went to an emergency room complaining of abdominal pain. PD1 was given medication and advised to see their personal physician upon returning to Los Alamos on July 22, 2005. PD1 returned to Los Alamos and was admitted to Los Alamos Medical Center (LAMC) on July 23, 2005. During the six-day stay in LAMC, a consulting pulmonologist treated PD1 for a "bronchial insult" resulting from the acid vapor exposure.

On August 3, 2005, after being released from the hospital, PD1 phoned the HSR-2 clinic and was interviewed by a nurse. Based on the results of that interview, PD1 was examined by the LANL Occupational Medicine Director (OMD). At about 4:30 pm that day, PD1 informed the C-SIC Group Leader of their condition. The C-SIC Group Leader informed the C Division Office of the situation. On August 4, 2005, upon learning of the LAMC medical team's treatment of PD1, the OMD determined that PD1 had suffered an occupational injury.

The LANL Health, Safety, and Radiation Division Institutional Industrial Hygiene and Safety Group (HSR-5) began investigating the accident on the morning of August 4, 2005. When LASO and LANL management determined that the length of PD1's hospitalization would require DOE/NNSA to conduct a Type B accident investigation, HSR-5 ceased their investigation. During the week of August 8, 2005, DOE/NNSA assembled a Type B Accident Investigation Board (the Board) and the investigation began on August 15, 2005. The Board's appointment memorandum is attached in Appendix A.

2.2 Emergency Response and Investigative Readiness

Prompt action by the postdocs to pour the aqua regia down the sink minimized the length of time that aqua regia vapors evolved. When PD1 and PD2 vacated Room 402, their proximate exposure to the vapors ended. Neither PD1 nor PD2 believed immediately after the accident that they had been injured by the exposure to aqua regia vapors. They did not go to the HSR-2 occupational medicine clinic for examination. C-SIC management did not realize that an accident had occurred, so no emergency response occurred.

Once C Division and HSR management learned of the accident, they began generating an Occurrence Reporting and Processing System (ORPS) report. The accident scene was taken into custody and the environs of Room 402 were preserved as they existed on August 4, 2005. Upon learning that PD1's hospital stay exceeded the DOE O 225.1A, *Accident Investigation* threshold for Type B investigations, LANL management notified LASO and LASO management directed that the ORPS investigation cease pending the arrival of the DOE/NNSA Board.

The Board concludes that LANL's actions demonstrated investigative readiness and that their activities enabled the Board's conduct of this investigation.

2.3 Description of Injuries

The LANL Site Occupational Medical Director (SOMD) advised the Board that two treating physicians, a medical toxicologist, and a pulmonogist were involved with PD1's diagnosis and treatment. Along with the SOMD, the team developed the medical opinion that the "chemical exposure" contributed to the hospitalization of PD1 at the Los Alamos Medical Center from July 23 to July 29, 2005. The medical team excluded other causes for PD1's diagnosis of right lower lobe pneumonia and right parapneumonic effusion through the process of a differential diagnosis thereby supporting the "chemical exposure" diagnosis. At the Board's request, PD1 was examined by a pulmonogist at National Jewish Hospital in Denver, CO on September 12, 2005. That pulmonologist stated "In my opinion, it is medically probable that this patient's work-related inhalational exposure to the airborne fumes produced during the production of aqua regia caused a toxic inhalational injury. Furthermore, it is medically probable that this initial injury was a significant aggravating factor (i.e. significant predisposing factor) in the later development of pneumonia and parapneumonic effusion in July".

2.4 Photographic Record of the Accident Scene

See Appendix C for photographic evidence and accident reconstruction.

3 ACCIDENT ANALYSIS

3.1 Accident Reconstruction

The Board reconstructed the accident scene in Room 402 on August 31, 2005. Smoke tubes were used to detect airflow patterns. Details of the testing procedures and results used in the reconstruction are contained in Appendix C. Calculations to estimate the exposure limits were performed as part of the accident reconstruction and are contained in Appendix D. Detailed information regarding the hazards associated with aqua regia vapor is contained in the Core Function 2 section of this report.

The Board concludes that aqua regia vapor concentrations in PD1's and PD2's breathing zones likely exceeded Short Term Exposure Limits (STEL) and that Immediately Dangerous to Life and Health (IDLH) Limits may have been exceeded.

4 LANL'S ISM SYSTEM EVALUATION

4.1 Background – Work Control Procedures at LANL

In 2003, the Laboratory Director appointed an Integrated Work Management Committee (IWMC) to enhance the Laboratory's work management processes for safely conducting work. Before the IWMC could develop, pilot, and implement a comprehensive set of work control improvements, significant accidents and a number of assessments at the Laboratory indicated immediate, interim actions were necessary.

On November 3, 2003, the LANL Health, Safety and Radiation Protection Division (HSR) issued Notice 0131, *Integrated Work Management – Interim Processes*. The Interim Process was applicable to all work requiring Hazard Control Plans, Facility Work Packages and Activity Hazard Analysis. The process entailed six critical steps, including: 1) Preparation of an Integrated Work Document (IWD) identifying work activities, sequential tasks/steps, and corresponding hazards and controls; 2) Validation of the IWD task/steps, hazards, and controls through a field walk-down; 3) Approval of the work activity; 4) Pre-job briefing based on the IWD tasks/steps, hazards and controls; 5) Release of the work; and 6) Periodic confirmation of readiness. In addition, Notice 0131 established roles, responsibilities and authorities for workers, persons in charge (PIC), management, and subject matter experts (SMEs).

The requirements of Notice 0131 were effective November 3, 2003 for all new work and certain high hazard operations. For all remaining work full implementation was required by January 1, 2004. The Notice required all divisions to submit an implementation plan to the Director's office by November 14, 2003. C Division did not develop an implementation plan in response to Notice 0131.

After several months experience with Notice 0131, the Integrated Work Management (IWM) process was revised in response to lessons learned and feedback from various organizations on concerns with the implementation of the process. On April 27, 2004, HSR issued Notice 0142, *Integrated Work Management – Interim Process,* rescinding Notice 0131. Notice 0142 clarified when an IWD was not necessary, described the level of detail necessary for work activity description, provided instruction on using existing safety documentation in place of required IWD information, and allowed use of cross-cutting IWDs for repetitive, low-hazard processes performed at multiple facilities. Implementation of Notice 0142 requirements began May 1, 2004.

On July 16, 2004, the Laboratory Director ordered a Laboratory-wide work suspension in order to ensure that the Laboratory was operating in a safe, secure, and compliant manner to meet its national security obligations.

The Laboratory issued LANL Implementation Procedure IMP 300, *Integrated Work Management for Work Activities* (IMP 300) on September 17, 2004. IMP 300 superseded Notice 142 and established the comprehensive LANL program for conducting work in a manner that protects people, the environment, property, and the security of the nation. The IMP outlined the IWM process to ensure that all LANL work is governed by the five steps of the ISM core functions: define the work; identify and analyze hazards; develop and implement preventive measures and controls; perform work safely, securely, and in an environmentally responsible manner; and provide feedback and strive for continuous improvement. IMP 300 provided a Hazard Grading Matrix to assist in designating work as Low, Moderate, or High Hazard Work and established IWD criteria based on hazard grading. IMP 300 also allowed the use of Standing IWDs for repetitive, moderate hazard work and established training requirements for all parties involved in the IWM process. Implementation milestones called for Responsible Line Managers (RLMs) to determine the hazard grade of existing activities and evaluate the adequacy of existing IWDs by November 1, 2004. Existing High-Hazard/Complex Activities IWDs were to meet IMP 300 requirements by January 31, 2005, and existing Moderate Hazard Activity IWDs were to be completed by May 31, 2005. Training activities for all active workers were also to be completed by May 31, 2005.

A Management Self-Assessment (MSA) of Chemistry Division Risk-Level 2/3 (RL2/3) activities was completed on September 8, 2004, and RL2 work was authorized to resume on September 27, 2004, following completion of pre-start compensatory measures. The Laboratory Readiness Review (LRR) for C Division RL3 activities was completed on October 15, 2004, and RL3 work was authorized to resume on October 20, 2004. Work resumption was authorized in stages, according to a resumption protocol and checklist, across the Division, as described in the C Division memo *Readiness to Resume RL2 Activities*, C-DO-04-076, September 21, 2004.

The corrective action plan for the C-Division MSA was managed on several levels. The overall, high-level actions were tracked in I-Track, a LANL issues management tracking database. However, the lower level actions required to accomplish the higher level issues were tracked in other C Division tracking systems. Some of the corrective actions had a projected completion dates in 2008. The C Division MSA corrective action plan listed an action to develop an IMP 300 implementation plan by August 31, 2005. The implementation plan was not developed and a Directorate-level implementation plan is being considered.

The Board concludes that, while expressing concern about this accident, C Division management has not shown a sense of urgency to ensure that proper work control processes were followed in C Division as demonstrated by failure to assess IMP 300 implementation in August 2005 as planned in the C Division MSA CAP.

The Board concludes that C Division management has not been proactive in assuring timely completion of outstanding corrective actions identified in the Management Self Assessment.

The Board concludes that the LANL practice of rolling-up safety and health *issues across the Laboratory and waiting for the development of Laboratory-wide solutions sometimes results in delays in addressing safety related issues at the activity level.*

On September 23, 2004, C Division issued POL-C-DO-007, *IWD Content Policy* to clarify requirements for content of IWDs in C Division. The policy states it is intended as an adjunct to Notice 0142 or IMP 300 requirements.

PD2 developed the IWD-C-SIC-0130-04, *Chemical Synthesis Using Anaerobic Schlenk and Aerobic Benchtop Techniques in a Low-Level Radiological Facility* that included glass cleaning activities in Room 402 of the Radiochemistry (RC-1) Building on October 6, 2004. M1 signed both the IWD validation and Work Release as PIC on October 7, 2004.

On February 9, 2005, LANL issued IMP 300.2, *Integrated Work Management for Work Activities*, and superseded IMP 300. IMP 300.2 provided additional guidance and assistance in completing IWM processes. IMP 300.2 allowed field changes to be made for minor changes in operational activities. However, "for activities covered by standing IWDs the PIC must walkdown the actual system of equipment and conduct a pre-job brief prior to work release. Such work requires only one pre-job brief if it is performed repetitively in the same location with the same workers…"

IWDs were the authorization and approval documents for all moderate and high hazard work performed at LANL. Standing IWDs were only allowed for moderate hazard work.

4.2 Core Function 1: Define the Scope of Work

4.2.1 How LANL's IWP Defined the Scope of Work

IMP 300 established the LANL Integrated Work Management (IWM) Process for doing work in a manner that protects people, the environment, property and the security of the nation. IWM defined the requirements for implementing the five core functions of DOE's Integrated Safety Management System (ISMS) at the activity level.

4.2.2 Worker Involvement in Developing Integrated Work Documents

The IWM process recognized the importance of direct involvement by the workers in controlling the risks, and the accountability of Responsible Divisions Leaders (RDLs) and the Responsible Line Managers (RLMs) for safety, security, and environmental protection. IMP 300 emphasized the following aspects of IWM:

- Management and worker accountability;
- Applying the workers' knowledge and experience;
- Providing integrated, worker-friendly documentation that defined work tasks/steps linked to specific hazards and unambiguous controls;

- Identifying a single Person-In-Charge (PIC) for each work activity;

- Providing independent oversight and facility coordination;

- Formally validating, releasing, and closing out work activities; and

- Feedback and continuous improvement.

IMP 300 stressed that workers must be actively engaged throughout the IWM process to provide the practical knowledge needed to fully identify the hazards and to ensure that controls were effective and procedures were workable. Workers were expected to perform their work within established controls systems and continually evaluate these systems to ensure they were adequate for the work they performed.

4.2.3 How LANL's IWM Process Established a Graded Approach

The IWM process allowed management judgment, tailoring and decision-making to address the broad range of hazards and complexity of work at the Laboratory. The RDLs and RLMs were required to:

- Establish processes to implement the requirements of IWM

- Determine the adequacy of controls to mitigate the risks

- Determine the competence of and commitment of workers to perform work in a safe, secure and environmentally responsible manner

- Assess operations to identify needed improvements

4.2.4 How the Original IWD Defined the Scope of work

The primary document governing the work that PD1 and PD2 accomplished in Room 402 was Integrated Work Document, IWD-C-SIC-0130-04, *Chemical Synthesis Using Anaerobic Schlenk and Aerobic Benchtop Techniques in a Low-Level Radiological Facility*. PD2, acting as IWD Preparer, completed the original version of this IWD on "10/6/04". The expiration date was originally listed as "5/31/2005" and was subsequently extended to "5/16/06" by an unidentified individual.

The Board concludes that even though IMP 300 was in effect at the time that PD2 developed IWD-C-SIC-0130-04, PD2's training records indicated that the required training for IWD Preparers had not been completed.

On page 5, the "Work Task/Step" column contained "General Concerns/Minimum Requirements for Laboratory Work in a Low-Level Radioactive Facility."

On page 11, the "Work Task/Step" column contained "Exploratory scale reagents such as: thorium and uranium metals and air-sensitive and stable organometallic complexes…"

On page 18, the "Work Task/Step" column contained "organic and inorganic acids (including aqua regia) and oxidizers (Only hydrochloric, sulfuric, nitric, phosphoric; and trifluoroacetic, and acetic, alkali metal salts of permanganate, silver reagents, and chromium oxides).”

On page 29 and 30, the “Work Task/Step” column contained “Cleaning glassware and fritted funnels, mechanical scrubbing or soaking of glassware using ammonia/hydrogen peroxide bath, soapy water, and organic solvents for glassware and aqua regia for fritted funnels.”

The Board concludes that the “Work Task/Step” column described a broad range of chemicals that potentially may be used, but did not identify a specific sequence of work task/steps in a manner that enabled subsequent hazard analysis.

4.2.5 How the C-SIC Field Change to the IWD Defined the Scope of Work

The work detailed in IWD-C-SIC-0130-04 was conducted in Room 402 from “10/6/04” until May 16, 2005, when the ventilation fan (FE-11) servicing the hoods in that room became inoperable.

On the morning of June 7, 2005 a meeting was held to discuss field changes to IWD-C-SIC-0130-04. The purpose of the meeting was to discuss completing tasks normally done in Room 402 in other locations with operational hoods. The focus of the meeting was to identify locations in Building RC-1 Alpha Wing and Room 409 that PD1 and PD2 could use to synthesize uranium tetrachloride (UCl_4). Present at the meeting were the C-SIC Group Leader, the C-INC Group Leader, M1, PD1, PD2, and others. Neither the Group Leaders nor M1 recalled discussing cleaning frits with aqua regia.

On page 1, of the field change to IWD-C-SIC-0130-04 the “Work Tasks/Steps” column contained “Field Change: The following procedures will be performed in TA-48/RC-1/Room 409 and Rm 407.” The “Work Tasks/Steps” column contained tasks associated with chemical synthesis, but did not contain mention of the task of cleaning glassware, the hazards of using aqua regia, or associated controls (i.e., a functional hood). M1 signed this change, on “6/7/05” and again on “6/24/05.” M1’s training records indicated that the training required for IWD PICs had not been completed.

On page 2, the Field Change “Work Tasks/Steps” column contained “The following procedures will be performed in TA-48/RC-1/Alpha Wing.” The “Work Tasks/Steps” column contained tasks associated with chemical synthesis, but did not contain mention of cleaning frits with aqua regia. M1 signed to approve this change on “6/7/05”.

4.3 Core Function 2: Analyze the Hazards

4.3.1 Hazards Associated with Aqua Regia

Aqua regia is a corrosive, fuming, yellow liquid prepared by mixing one volume of nitric acid with three volumes of concentrated hydrochloric acid. It was so named as “Royal Water,” by alchemists because it dissolves gold and platinum, the “royal metals,” which do not dissolve in nitric or hydrochloric acid alone. Its fumes and yellow to orange color are caused by the reaction of nitric acid (HNO_3), with hydrogen chloride (HCl), to form nitrosyl chloride (NOCl), chlorine (Cl_2), and water. Both chlorine and nitrosyl chloride are also volatile. The nitrosyl chloride further decomposes to nitric oxide (NO) and nitrogen dioxide (NO_2), and chlorine gas as illustrated by the following equations: (a more detailed account of Aqua regia reactions is in Appendix D).

$$HNO_3 + 3HCl \rightarrow NOCl + Cl_2 + 2H_2O$$

$$2NOCl \rightarrow 2NO + Cl_2$$

$$2NO + O_2 \rightarrow 2NO_2$$

$$HNO_3 + metals \rightarrow NO_2 + metals^+ + H_2O$$

Inhalation of acid vapors can cause irritation or corrosive burns to the upper respiratory system. Lung irritation and pulmonary edema can occur. It may also cause delayed lung injury and can be fatal. Airway problems may arise from laryngeal edema and inhalation exposure. Acid vapor could present a hazard from a single acute exposure or from repeated exposures over a long time period. The inhalation hazard increases at higher temperatures.

Reactants and products that may present exposure hazards to workers using aqua regia were identified from industrial hygiene references, resources available on the internet, and material safety data sheets (MSDSs). These compounds are listed in Table 1. Exposure limits from the American Conference of Governmental Industrial Hygienists (ACGIH) and the Occupational Safety and Health Administration (OSHA) are listed for each compound. Exposure concentrations, determined by the National Institute of Occupational Safety and Health (NIOSH) as immediately dangerous to life or health (IDLH) are also listed.

Table 1. Compounds of exposure concern for work with aqua regia

Compound	MW	ACGIH TLV	ACGIH STEL	OSHA PEL	NIOSH IDLH	LC_{50}, ppm
Reactants						
Hydrochloric Acid, HCl (37% Hydrogen Chloride)	36.46		2 ppm (ceiling)	5 ppm (ceiling)	50 ppm	3124 (30 min, rats)
Nitric Acid, HNO_3 70%	63.01	2 ppm	4 ppm	2 ppm	25 ppm	334 (30 min, rats)
Products						
Chlorine, Cl_2	71	0.5 ppm	1 ppm	1 ppm (ceiling)	10 ppm	293 (1 hr, rats)
Nitrosyl Chloride, NOCl	65.47	not established	not established	not established	not established	35 (1 hr, species*)
Nitrogen Dioxide, NO_2	46	3 ppm	5 ppm	5 ppm (ceiling)	20 ppm	115 (1 hr, rats)
Nitric Oxide, NO	30	25 ppm		25 ppm	100 ppm	1068 (duration*, rats)

* Unspecified in the available literature
Note: Nitric oxide will oxidize in air to produce nitrogen dioxide (per MSDS).

4.3.2 How the Original IWD Analyzed the Hazards

Many activities in C Division laboratories involved the use of relatively small quantities of hazardous chemicals on a non-production basis. Such activities fell within the scope of OSHA regulation 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories*. Where 1910.1450 is properly applied, it supersedes, for laboratories, the requirements of all other OSHA health standards in 29 CFR part 1910, Subpart Z, except: employee exposure to a specific permissible exposure limit; prohibition of eye and skin contact where specified by any OSHA health standard; and exposure monitoring and medical surveillance requirements where an OSHA action level or permissible exposure limit is routinely exceeded.

29 CFR 1910.1450 requires the laboratory employer to develop a Chemical Hygiene Plan (CHP). The CHP is a written program developed and implemented by the employer which sets forth procedures, equipment, personal protective equipment and work practices to protect employees from the health hazards presented by hazardous chemicals used in a particular workplace. LANL developed a CHP as part of LIR 402-510-01.1, *Chemical Management*. The CHP is applicable to C Division research activities involving chemicals.

In developing 29 CFR 1910.1450, OSHA recognized the technical expertise and knowledge of chemists and other laboratory personnel regarding laboratory hazards associated with chemical usage. Because of the historic application of 29 CFR 1910.1450 to C Division activities, hazard control documents for C Division were not required to fully address the health hazards associated with chemicals. The LANL IWM work control processes outlined in IMP 300, however, did not maintain such an exclusion for chemical hazards. The Board confirmed that C Division personnel and HSR safety and health support staff did not fully recognize the significance of the change from CHP to IWM requirements concerning the hazard analysis and control identification for activities involving chemicals. As a result, many IWDs for research involving chemicals referenced HCPs that did not address health hazards associated with chemicals and those IWDs did not analyze the chemical hazards either.

IWDs were intended to record activity-specific tasks, hazards, and controls. On page 30 of IWD-C-SIC-0130-04 "fumes" were listed as a hazard, but the potential accident, target organs, or effects on the workers were not identified. PD2 did not identify significant hazards involved with making and using aqua regia to clean frits; specifically, the formation of oxides of nitrogen, nitrosyl chloride, chlorine, and other toxic compounds were not identified as hazards. Neither delayed injury, lung damage, nor possible death as a result of unprotected exposure to aqua regia vapors was listed. Because the extent of potential health effects were not recognized, PD2 graded the hazard for the frit cleaning activity as "moderate." Based on the instruction in IMP 300, Attachment 1, *Hazard Grading Matrix*, the hazard should have been graded as "high" due to the work involving hazards that "could cause critical or catastrophic harm to people…such as severe or fatal injuries, life shortening disease, or permanent disability."

The Board concludes that the hazards involved with making and using aqua regia were not fully analyzed, to include the formation of oxides of nitrogen, nitrosyl chloride, chlorine, and other toxic compounds.

The Board concludes that the potential accident, target organs or effects on the workers were not identified. The delayed injury, lung damage or possible death was not identified as a consequence of unprotected exposures to aqua regia.

On page 11, the "Work Task/Step" column contained "Exploratory scale reagents such as: thorium and uranium metals and air-sensitive and stable organometallic complexes…" IWD-C-SIC-0130-04 did not identify chemical hazards associated with the use of such reagents nor did the referenced Hazard Control Plans (HCPs).

The Board concludes that many existing C Division HCPs were not required to fully analyze the hazards associated with chemical operations because of the previous coverage of these operations under 29 CFR 1910.1450, Occupational Exposure to Hazardous Chemicals in Laboratories.

The Board concludes that the C Division practice of having postdocs develop IWDs without first ensuring that they were trained in hazard recognition and *analysis resulted in some IWDs that did not establish a comprehensive set of protective measures.*

The Board concludes that IWD-C-SIC-0130-04 incorrectly graded the hazard associated with making and using aqua regia as a moderate hazard; the hazard grading should have been high hazard in accordance with IMP 300, Hazard Grading Matrix.

4.3.3 How the C-SIC Field Change to the IWD Analyzed Hazards

The field change to IWD-C-SIC-0130-04 for tasks to be performed in TA-48/RC-1 Room 409 and 407 or TA48/RC-1 Alpha Wing did not identify the task of glass cleaning or reiterate hazards associated with making and using aqua regia.

At the meeting on the morning of June 7, 2005 C-SIC management focused the discussion on research activities and did not ensure that PD1 and PD2 clearly understood the scope of the changes made to IWD-C-SIC-0130-04. M1, as the PIC did not conduct a pre-job brief in accordance with the IMP 300 instructions. Per the procedure, M1 should have taken PD1 and PD2 to the locations identified in the field change to the IWD-C-SIC-0130-04 and walked them through the upcoming activities.

The Board learned that the synthesis of uranium tetrachloride involved toxic chemicals, evolved toxic products such as phosgene and chlorine gas, and involved methylene chloride, an OSHA-regulated carcinogen as a rinsing agent. IWD-C-SIC-0130-04 did not identify or analyze hazards associated with these chemicals and the page 1 of the Field Change stated “No new hazards” were associated with the task.

The Board concludes that, as written, the Field Changes for TA-48/RC-1 Room 409 and 407 and TA-48/RC-1/Alpha Wing did not identify the hazards and controls necessary for the tasks identified on the IWD.

The Board concludes that IWD-C-SIC-0130-04 incorrectly graded the hazard associated with uranium tetrachloride synthesis as a moderate hazard; the hazard grading should have been high hazard in accordance with IMP 300, Hazard Grading Matrix.

4.4 Core Function 3 Development and Implementation of Controls

4.4.1 DOE/LANL Work Smart Standards

DOE-HDBK-1148-2002, *Work Smart Standards (WSS) Users Handbook*, dated February 2002, states that the WSS program is a product of the DOE Necessary and Sufficient closure process. Within the contractual framework of ISMS, the Department of Energy Acquisition Regulation (DEAR) clause 970.5204-78, *Laws, Regulations, and DOE Directives* requires LANL to identify environment, safety and health requirements applicable to the Laboratory. The WSS process was used to develop the set of contractually binding standards that both DOE and the contractor agreed were sufficient to implement DOE’s ISM System at the Laboratory.

The University of California operates LANL under a Management and Operating (M&O) Contract with the Department of Energy. The Board considered the following Contract W-7405-ENG-36 Appendix G, *List of Applicable Directives* requirements germane to this accident:

- Occupational Safety and Health Act, 1970, Public Law 91-596, Sections 4, 5(a)(1), 6, 8.
- 29 CFR 1910, *Occupational Safety and Health Standards*
- DOE O 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees,* Attachment 2, Sections 6, 7, 8, 14, 16, 18, 19, and 20
- DOE O 5480.19, Change 2, *Conduct of Operations Requirements for DOE Facilities*.
- ACGIH, 1997, *Threshold Limit Values*

The Board determined that the WSS in the contract between DOE and the University of California (UC) correctly identified standards necessary to facilitate safe operations in laboratories such as TA-48, RC-1, Room 402. LANL had formalized controls for working with toxic chemicals, including IWD-C-SIC-0130-04, under which the frit cleaning was performed.

Safety and health professionals, including industrial hygienists, were assigned to C Division. C Division was the line management organization responsible for ensuring that M1, PD1, and PD2 performed operations in areas under their cognizance in a safe manner. Even though the appropriate safety and health requirements were in place (the WSS), C Division did not fully implement them.

The Board concludes that Chemistry Division did not implement the safety and health requirements established in the LANL contract in a manner that ensured workers were protected from serious, recognized workplace hazards, such as aqua regia vapors.

4.4.2 How the Original IWD Developed Controls

Controls for work with hazardous chemicals typically include: 1) product substitution, 2) engineered controls, 3) administrative controls, and 4) use of personal protective equipment (PPE). C Division had not been able to identify an acceptable substitute for aqua regia that would effectively clean glassware without posing unacceptable environmental concerns. C Division had considered disposing of the frits rather than cleaning them, but had not established that practice. Administrative controls identified in several C Division IWDs for using aqua regia to clean glassware were a) using the correct ratio of acids to make aqua regia, b) cleaning frits in a hood, and c) disposing of aqua regia by washing it down an appropriate drain.

Part B of IWD-C-SIC-0130-04 *Chemical Synthesis Using Anaerobic Schlenk and Aerobic Benchtop Techniques in a Low-Level Radiological Facility* included a column titled “Controls, Preventive Measures, And Boundaries.” The controls in the IWD for working with aqua regia included using the prescribed ratio of acids to mix aqua regia, and using aqua regia to clean frits in a hood.

The “Controls, Preventive Measures and Boundaries to Include Engineering Controls” column contains “All work to be performed in a fume hood” and “Aqua regia will always be worked with in hood for cleaning frits, and will be disposed of by washing down the correct drain with copious amounts of water”.

IMP 300 allowed the preparers to reference HCPs in activity-specific section of IWDs to assist in meeting the requirements to provide activity-specific information. The preparer must ensure that all necessary required IWD information is provided. Chemical-specific control measures were not identified in the IWD-C-SIC-0130-04 format or the referenced HCPs.

The Board concludes that many existing C Division HCPs did not fully identify controls for the hazards associated with chemical operations because of the previous coverage of these operations under 29 CFR 1910.1450, Occupational Exposure to Hazardous Chemicals in Laboratories.

4.4.3 How the C-SIC Field Change to the IWD Developed Controls

On page 1, a 6/24/05 field change to “Controls, Preventive Measures and Boundaries to Include Engineering Controls” column contained a requirement for an “Admin Control: Sash will be lowered on hood.”

On Page 2, the field change “Controls, Preventive Measures and Boundaries to Include Engineering Controls” column did not identify engineered or administrative controls for aqua regia.

Also on Page 2, the field change “Controls, Preventive Measures and Boundaries to Include Engineering Controls” column did not identify engineered or administrative controls for the synthesis of uranium tetrachloride.

The original IWD-C-SIC-0130-04 only authorized making and using aqua regia to clean frits in Room 402 in a functional laboratory hood. The appropriate engineered control, a functional laboratory hood, was available in another room, but PD1 and PD2 did not move the frit cleaning to that location. The Nederman® portable ventilation system in operation at the time of the accident was never intended to provide ventilation for frit cleaning on the benchtop.

The Board concludes that the field change to IWD-C-SIC-0130-04 did not document that a pre-job briefing or operational walk-down was conducted in the manner specified in IMP 300.

The Board concludes that the C-SIC personnel involved with the preparation, review, approval, and Field Change to IWD-C-SIC-0130-04 were not knowledgeable of the application of types of hazard controls (i.e., administrative vs. engineering).

The Board concludes that an available, identified engineered control (i.e., a functional laboratory hood) was not used.

4.5 Core Function 4: Perform Work Within Controls

On or about May 16, 2005 maintenance of the ventilation system in TA-48, Building RC1 began and resulted in the hood in Room 402 being out of service on June 7, 2005. The dry box in Room 402 had been piped into the hood ventilation system. The dry box vent removes nitrogen used to pressurize the box. The oxygen and water are removed by continuous circulation through a catalyst bed. Because the purged nitrogen contained vapors from the solvents used in the dry box, IH1 decided to use the Nederman® to vent this system to the outdoors rather than into the room. The Nederman®, a portable ventilation system designed for welding fume control, was modified so that the purged nitrogen from the dry box was vented to the outside through an opening cut in a plastic window pane. This system was never intended to provide ventilation for any chemical operations other than those inside the dry box.

The Board concludes that M1 and IH1 intended that the Nederman® was to be used solely to vent the dry box.

Because IWD-C-SIC-0130-04 stated that work with aqua regia must be performed within a hood, PD1 and PD2 were not authorized to work with aqua regia on the benchtop in Room 402 on June 7, 2005. PD1 and PD2 made and used aqua regia on a bench top. PD1 and PD2 wore the standard PPE required for entering Room 402: lab coat, safety glasses with side shields, and gloves. Respiratory protection appropriate for work outside of a hood was neither provided nor routinely available.

When PD1 became "sick" from the vapor, PD2 then poured the aqua regia into the frits in an attempt to complete the task. When PD2 realized that the acid vapor was too intense, the beaker containing the aqua regia was flushed with water down the drain in Room 402. They did not inform M1 immediately. PD1 and PD2 did not post or cordon off Room 402 after they evacuated in order to warn others not to enter. They reentered the room to perform work in the dry box, without consulting M1 and potentially exposed themselves to a second acid vapor exposure.

The original IWD specified that work with aqua regia would be performed in a hood. The hoods in Room 402 were not available due to the exhaust fan being shut down for repair. The hood sashes were closed and the remaining opening sealed with plastic and tape. PD1 and PD2 did not move the frit cleaning to another room that had functional hoods.

When interviewed, PD2 discussed evaluating the presence of the Nederman® portable ventilation system, the portable evaporative coolers, and Room 402's open doors and considered that there was sufficient airflow to make and use aqua regia on the bench top. PD2 recalled that at some time prior to June 7. 2005, PD2, PD1, and M1 had discussed the situation and agreed that the airflow should be sufficient for frit cleaning. PD1 did not mention such a discussion and M1 stated that no such discussion ever occurred. On June 1, 2005 PD1 sent an e-mail to M1 listing tasks that would require a functional laboratory hood to complete; frit cleaning was among the tasks listed.

At the meeting on the morning of June 7, 2005 C-SIC management focused the discussion on research activities and did not ensure that PD1 and PD2 clearly understood the scope of the changes made to IWD-C-SIC-0130-04. M1, as the PIC, did not conduct a pre-job brief that fully complied with the requirements of IMP 300 instructions. Per IMP 300, M1 should have taken PD1 and PD2 to the locations identified in the field change to the IWD and walked them through the upcoming activities.

The Board concludes that PD1 and PD2 were not clearly informed that the purpose of the Nederman® was solely to ventilate the dry box and was not intended to provide ventilation for other activities in Room 402.

The Board concludes that frit cleaning with aqua regia was performed on the benchtop in Room 402 without using the engineered control stated in IWD-C-SIC-0130-04 (i.e., a functional laboratory hood).

The Board concludes that the Field Changes for TA-48/RC-1 Room 409 and 407 and TA-48/RC-1/Alpha Wing did not identify the hazards and controls necessary for the tasks identified on the IWD.

The Board was unable to verify what M1, PD1, and PD2 said to each other on or before June 7, 2005 regarding making and using aqua regia in Room 402. The Board considered information gained from interview transcript reviews, follow-up interviews, and each individual's factual accuracy reviews of their own transcripts, but could not resolve the differing accounts of what was said before the accident. The Board interviewed over 20 people familiar with the accident or with M1's, PD1's, or PD2's professional demeanor in an attempt to determine the validity of each individual's recollections.

The Board concludes that there was confusion among M1, PD1, and PD2 as to where the frits were to be cleaned and what controls were absolutely necessary.

4.6 Core Function 5: Feedback & Improvement

4.6.1 Near Miss Reporting

PD1, PD2, and M1 failed to report the exposure to acid vapors in Room 402 on June 7, 2005, to either C Division management or HSR. The Board reviewed the content of LANL LIR 402-130-01.3, *Abnormal Event* and found that it required workers to report injuries/illness, environmental incidents, property damage, radiological incidents, and reportable occurrences. The only place near miss events were mentioned in the LIR is in the definition of a "reportable occurrence." The Board noted that it is a management decision to classify an event as "reportable" under the appropriate DOE Occurrence Reporting and Processing System (ORPS) criteria.

The Board concludes that none of the C-SIC employees who were aware of the aqua regia incident in Room 402 believed that a reportable accident had occurred.

The Board concludes that the accident was not reported to LANL management as required by LIR 402-130-01.3, Abnormal Events.

Section 6.3, *Training*, of the LIR 402-130-01.3 stated that training for this LIR was to be accomplished through General Employee Training (GET) for new employees and through organizational-specific training for follow-up actions on specific types of abnormal events, as required. The LIR also required line managers to ensure that current workers were briefed on LIR reporting requirements. The Board reviewed the content of LANL GET Manual and found no mention of reporting near miss events in the course Manual.

DOE Policy (P) 450.7, *Department of Energy Environment, Safety and Health (ES&H) Goals*, highlighted the importance of accurately reporting ES&H incidents. DOE P 450.7 stressed the importance of fostering a work environment that encourages free and open expression of ES&H concerns where employees have no fear of reprisal or discrimination for reporting such concerns and where non-reporting is viewed as an unsafe practice that presents a threat to workers and the public.

The Board conducted interviews with a wide range of C-Division post doctoral, student, and technical staff employees. The Board found that almost all employees felt that they could exercise stop work authority and report incidents without fear of reprisal. The Board also found a wide variety of answers regarding the definition of "near miss."

The Board concludes that the C Division management did not clearly communicate expectations for reporting near miss events.

The Board concludes that C Division staff members interviewed were generally comfortable voicing safety concerns without fear of retribution, and believed that management would follow up on their concerns.

LANL LIR 402-130-01.3, *Abnormal Events*, dated December 21, 2000 required that workers "notify the safety and environment line manager/designee of all abnormal events as soon as possible."

On June 8, 2005, PD1's spouse contacted IH3 concerning PD1's potential exposure to aqua regia vapors. IH3 did not ensure this information was provided to the proper authorities. On June 29, 2005, PD1's spouse again contacted IH3. IH3 did not report this contact. On July 25, 2005, while PD1 was in the hospital, PD1's spouse again contacted IH3. Sometime after this third contact, IH3 reported the accident to the Acting Division Leader of HSR Division.

The Board concludes that the accident was not reported to LANL management as required by DOE P 450.7, *Department of Energy Environment, Safety and Health (ES&H) Goals.*

The Board concludes that the failure to report the accident deprived LANL management the opportunity to take steps to minimize the severity of the injury.

4.6.2 LASO/LANL Response To Previous Accidents

Recent accident investigations conducted by DOE and LANL of importance to this investigation were reviewed. The purpose of the review was to assess NNSA/LASO and contractor performance in developing, timely completion and effectiveness of corrective actions to address past Judgments of Need. The review included:

- Two Workers Injured by a Chemical Explosion at TA-9-21 (May 27, 2005, LANL)
- LANL Investigation of a Laser Eye Injury (July 14, 2004)
- Independent Investigation of a Five Worker Exposure to Toxic Vapors at TA-55, PF-4 (September 27, 2003, LANL)
- Independent Investigation of an Acid Spray and Skin Contamination (July/August 2003, LANL)
- Type B Accident Investigation of the August 5, 2003 Plutonium-238 Multiple Uptake Event at the Plutonium Facility (DOE)
- Type B Accident Investigation of the Mineral Oil Leak Resulting in Property Damage at the Atlas Facility, January 2001 (DOE)
- Type A Accident Investigation Of The March 16, 2000 Plutonium-238 Multiple Intake Event at the Plutonium Facility (DOE)

The Board reviewed the Corrective Action Plan (CAP) developed in response to the Type A Accident Investigation of the March 16, 2000 Plutonium 238 Multiple Intake Event at the Plutonium Facility. As reported in the DOE Corrective Action Tracking System (CATS) the corrective action plan (LANL-07/24/2000-R-AIA) developed in response to the Type A Accident Investigation was completed on April 28, 2005. The last LANL action as recorded in I-Track was verified complete on April 14, 2005. The last NNSA/LASO corrective action (JON 14, Action 3) was completed on April 6, 2005.

JON 14 of the Type A Investigation stated "NNSA/DP needs to ensure that line management oversight process at LANL is being performed and is effective as specified by DOE Policy 450.5, *Line Management Oversight*, and DOE Standard DOE-STD-1063-97, *Facility Representatives*." Corrective Action number 3 addressing that JON was "Verification of successful implementation of LANL corrective actions" and the associated deliverable was "Written DOE acknowledgement to LANL that LANL has a robust, rigorous, and credible self-assessment program required by DOE P 450.5."

In January 2005, LASO, through the Change Control Board, changed Corrective Action number 3 to "Verify LANL develops, manages as a project, a Corrective Action Plan for the implementation of a robust, rigorous, and credible self-assessment program as required by DOE 450.5" and the deliverable to "Memorandum identifying NNSA concurrence that the implementation of the PAAA corrective action plan (CAP) (NTS-ALO-LA-LANL-2004-0018) will result in a credible self-assessment program as required by DOE Policy 450.5."

The Board concludes that the change of JON 14 Corrective Action 3 and deliverable removed from NNSA/LASO the responsibility to verify LANL has a robust, rigorous, and credible self-assessment program as required by DOE P 450.5.

The Board concludes that the length of time (57 months) that LASO/LANL took to address the JONs arising from the March 2000 accident is not indicative of organizations with a strong commitment *to using feedback from accident experience to drive improvements in safety culture.*

The Board reviewed the CAP developed in response to the Type B Accident Investigation of the August 5, 2003 Plutonium 238 Multiple Uptake Event at the Plutonium Facility. The investigation report issued 13 JONs; eight were addressed to LANL and five were addressed to LASO/NNSA. LANL identified 25 corrective actions to address the eight JONs they were assigned to correct. At the time of this investigation, 28% of the corrective actions were overdue for completion. Five of those actions were overdue by more than nine months. One action was overdue by more than 11 months and one action was overdue by more than one year.

In February 2004 LASO assigned a responsible person to "manage" the CAP. LASO established a change control board process to manage changes to the CAP. The LANL and LASO corrective actions were tracked separately. The LASO corrective actions were tracked as an individual effort; no formal system was used. LANL managed the corrective actions in the LANL Issue Management Program's I-Track system.

LASO provided the Board with the CAP and change control actions associated with the CAP. The Board requested, and did not receive, the current status of corrective actions associated with JONs 9 through 13 assigned to LASO in the Type B Accident Investigation of the August 5, 2003 Plutonium-238 Multiple Uptake Event at the Plutonium Facility.

The Board concludes that LASO's informal system for tracking issues contributed to LASO's ineffective management of corrective actions associated with the Type B CAP that were assigned to NNSA/LASO.

4.6.3 LASO Oversight Staffing

In April 2005, 12 personnel were assigned to the Facility Representative (FR) team. The LASO organization chart dated August, 22, 2005 showed 17 personnel assigned to the Facility Representative Team. However, due to competing activities and priorities with the office, only 4 of these personnel were working full time at their assigned facilities during the time frame of the accident. LASO completed a staffing analysis and sent the results to Jerald S. Paul (NA-1) in a memorandum dated January 6, 2005. The results of the analysis showed the "effective" FR coverage was 5.5 full time equivalent (FTE) employees. The analysis concluded that "LASO requires approximately 19 field deployed facility representative positions be staffed to ensure the 12 FTE FRs coverage occurs in the most hazardous facilities. Two additional FR Team Leader positions were also required to provide day-to-day direction to the FRs." The staffing analysis was completed in accordance with guidance from NA-1 in a memorandum titled *Promulgation of Headquarters Guidance on Facility Representative Training and Facility Representative Staffing Analysis*, dated October 13, 2004. At the time of the analysis, no FR staff was assigned duties at TA-48.

The limited Facility Representative and Safety and Health SME resources were recently aggravated by a rising number of competing priorities such as the recent LANL work suspension and resumption of activities for safety and security reasons, "federalized" activities (a locally used term to indicate a high degree of federal involvement to achieve Departmental priorities), and contract competition and selection activities. This has resulted in LASO focusing the FR coverage on the nuclear (higher hazard category) facilities and reduced oversight at less than Hazard Category 3 radiological facilities.

LASO oversight activities were accomplished at two levels. SMEs were focused on assuring programmatic requirements were met, while the FRs were relied upon to assure the programmatic requirements are implemented. Within the Radiological Controls Program, the health physicist provided the FRs with comprehensive checklists that were used to assess the effectiveness of the program implementation by LANL.

The Board concludes that the reduced LASO oversight and field presence resulted in a lost opportunity for the LASO to observe and assess the Laboratory's implementation and effectiveness of the Integrated Work Management processes including development and implementation of the Integrated Work Documents.

As LASO was previously organized, the facilities operations staff of about 20 positions (FR and S&H SMEs) had seen a turnover of approximately 41 personnel in the last ten years. The LASO office has had 18 managers in the last 20 years. LASO personnel reported that the high turnover in personnel had resulted in challenges to LASO management in assuring sufficient, well qualified and knowledgeable safety staff that was fully engaged in LANL oversight activities. The Board requested and did not receive official attrition data from LASO.

LASO stated a staffing level increase was requested from NNSA for FY-2006 from 111 FTEs to 180 FTEs. NNSA approved 129 FTEs. A breakdown by position was not immediately available.

The Board concludes that the lack of LASO presence in Technical Area 48 allowed the C Division IWD training and implementation weaknesses identified by the Board to go undetected.

4.6.4 LASO Line And Independent Oversight And Enforcement Actions

LASO recently established an oversight schedule integrating LASO FR/SME and LANL oversight activities. The Integrated Oversight Schedule was developed by reviews of the results of oversight activities by both LANL and LASO. Areas of weakness were identified for upcoming oversight activities. Whether the oversight was conducted by LANL or LASO was negotiated based upon area of organizational responsibility and the assessed weakness or need for improvement.

Annually, LASO appraised contractor performance in accordance with contract requirements. Los Alamos National Laboratory Contract No. W-7405-ENG-36, Section H.007, *Performance-Based Management*, established Appendix F, *Standards for Performance*, Section

H.007 required that "NNSA/DOE will use the Contractor's Evaluation Report as the primary basis for the annual appraisal of Contractor performance, recognizing that NNSA/DOE will take into account other pertinent information, including that performance against each Strategic Performance Objective is subject to timely availability of adequate funding, as well as operational oversight, internal and external program reviews and audits consistent with the intent of this Contract, in determining the annual appraisal for performance."

Modification M592 to the contract established the FY2004 Appendix F, Performance Objective #8 that contained measures to: "Maintain a secure, safe, environmentally sound, effective and efficient operations and infrastructure basis in support of mission objectives." The LASO completed the FY2004 *Annual Performance Appraisal of the University of California's Management and Operation of Los Alamos National Laboratory* and concluded that all criteria in Section 8 rated "Unsatisfactory" performance. Subsequent to that rating, Modification M597 reduced the available Program Performance Fee by 51% for the FY 2004 evaluation period because of the performance failures.

In April 2003 and June 2004, NNSA, coordinating with the Department of Energy's Office of Price-Anderson Enforcement (OE), issued Preliminary Notices of Violations (PNOVs) and Proposed Civil Penalties. The PNOVs assessed proposed civil penalties in the amounts of $385,000 (waived by statute) and $770,000 (waived by statute) respectively against LANL. Relevant to this investigation, were the number of work control deficiencies identified in the OE report and cited in the PNOVs and the actions taken by NNSA.

The Board concludes that LASO was aware of LANL's ongoing poor performance with regard to ISMS implementation and took action in accordance with the terms and conditions of the contract.

The Board concludes that NNSA recognized continuing issues related to the effective implementation of work controls requirements (ISMS) and coordinated appropriate action with the Office of Enforcement.

4.6.5 FR Oversight Processes And Activities

The Board reviewed FR generated surveillance reports from April 2003 to September 2005. Prior to the July 2004 work suspension, FR surveillance reports were compiled quarterly and sent to the contractor by a letter from the Contracting Officer Representative. Beginning with the July 2004 work suspension, FRs no longer compiled quarterly reports. No reports were compiled or forwarded to the contractor from about July 2004 until January 2005. In January 2005, LASO initiated a weekly reporting process for the FRs and SMEs. The FRs and SMEs completed a form electronically and e-mailed it to the cognizant LANL Division Director and copied the FR Team Lead.

The FR Team Leader compiled a roll-up report from the FR weekly reports. The roll-up report was sent to the Assistant Manager for Facility Operations who highlighted significant issues or concerns and forwarded the report to other senior LASO and contractor management by e-mail. FRs and SMEs tracked their own findings and concerns as an individual effort. In the time period since April 2003, no surveillance activities were documented at TA-48 or RC-1.

4.6.6 FR Coverage

Prior to 2003, the FR assigned responsibilities for TA-48 spent about 25% of available time at TA-48 and about 40% at TA-3 facilities. No surveillance reports could be located that documented surveillance activities at TA-48 since at least April 2003.

DOE P 450.7, *Department Of Energy Environment, Safety and Health (ES&H) Goals*, requires that site-specific ES&H goals be established and approved by the Cognizant Secretarial Officer, and that progress against those measures be reported quarterly through the Cognizant Secretarial Officer to their Under Secretary. NNSA Deputy Director for Defense Programs issued a memorandum on December 6, 2004, subject: *ACTION: National Nuclear Security Administration (NNSA) Environmental Safety & Health Performance Data*. That memorandum required the eight site offices to begin reporting ES&H data to NA-10 on a quarterly basis beginning with data collected during the first quarter of fiscal year 2005. The Board requested and did not receive a strategic plan from NNSA or site-specific ES&H goals and measures.

The Board concludes that NNSA-approved site-specific ES&H goals were not established, LASO has received no guidance from NNSA regarding the development of site-specific ES&H performance goals, and no quarterly reporting to NNSA is occurring for site-specific ES&H goals.

4.7 Guiding Principles

4.7.1 Guiding Principle 2: Clear Roles and Responsibilities

IMP 300 assigned clear roles and responsibilities to RDLs, RLMs, PICs, IWD Preparers, and workers. For IWD-C-SIC-0130-04, PD2 signed as the Preparer, M1 signed as the PIC, PD1 and PD2 signed as workers.

The Board concludes that although C-SIC employees involved in this accident believed that they understood their roles and responsibilities for generating and managing IWDs, they had not received required training nor were they fully aware of their responsibilities under IMP 300.

4.7.2 Guiding Principle 3: Competence Commensurate with Responsibilities

The Board learned of specific toxic attributes of aqua regia vapor that were not fully understood by LANL chemists and industrial hygienists. Their academic training did not acquaint them with specific aqua regia hazards. Literature searches revealed that little information on the topic was readily available.

Researchers were responsible to protect themselves and others from chemical hazards. PD1 and PD2 demonstrated some awareness of aqua regia hazards. As doctoral chemists with years of laboratory experience, PD1 and PD2 were aware that aqua regia is a hazardous substance. Both stated that they made and used it routinely to clean frits and that they did it safely by always doing it in a functional laboratory hood. They demonstrated recognition of the hazard when they signed the original IWD requiring aqua regia to be made and used in a hood. The Board found that although aqua regia is universally recognized as a hazardous substance, the specific components of aqua regia vapor, the specific target organs, and the injury mechanisms specific to exposure were not well understood.

The Board concludes that while PD1 and PD2 were competent to perform their duties as chemists they did not fully understand the hazards associated with making and using aqua regia.

IMP 300 identifies required and suggested IWM training for key participants. Also, the Virtual Training Center contained an Integrated Work Management Training Matrix in that specified the required training for preparers, persons in charge (PICs), workers and others. A review of selected training records indicated that M1, PD1, and PD2 were not fully trained in the roles of IWD preparers and Person in Charge (PICs). The IWDs that PD1 and PD2 had prepared were largely compliant with IWM, indicating that they were familiar with the process.

C-SIC training coordinator stated that training recordkeeping needed improvement. For example, the training database did not always accurately record class completions, so employees often had to complete classes multiple times to receive credit. There was also lag time in updating the individuals training records. This was not consistent with the conduct of operations expectations for effective recordkeeping as outlined in DOE Order 5480.19. Even before learning of the accident the C-SIC Group Leader had been updating training plans by requiring each worker to complete a questionnaire about the types of work that they perform. These questionnaires were then used to update individual training plans.

The Board concludes that M1, PD1 and PD2 were not fully trained or qualified to perform the roles of IWD Preparer or PIC.

The Board concludes that C Division management did not assure that employees completed training required by IMP 300 for IWD Preparers and PICs prior to authorizing work under IWD-C-SIC-0130-04.

The Board concludes that without reliable, accurate, and timely training records, C-SIC management would find it difficult to determine which workers are qualified to perform specific tasks.

4.7.3 Guiding Principle 4: Balanced Priorities

Guiding principle 4 states that protecting the public, the workers, and the environment shall be a priority whenever activities are planned and performed.

The purpose of a postdoctoral appointment was to complete research and publish the experimental results in a short time frame to advance their career. Because the postdoctoral period was limited, postdocs, in general, were frustrated by any condition that inhibited their ability to accomplish research. The delays created by the work suspension from July 16, 2004 to September 27, 2004, the development of the IWD for work in Room 402 approved October 7, 2004, and the May 16, 2005 ventilation shutdown in Room 402 resulted in a sense of urgency for postdocs to complete their research.

M1 was eager to find a laboratory for PD1 and PD2 to perform synthesis of uranium tetrachloride. M1 located an alternate location for PD1 and PD2 to continue their research activity in a safe manner.

The Board concludes that M1's, PD1's, and PD2's drive to accomplish research activities took priority over housekeeping activities such as frit cleaning, even though the hazard level associated with frit cleaning was graded by PD2 as equivalent to research activities.

4.7.4 Guiding Principle 7: Work Authorization

IWM was the process for authorization of all activity-level work at LANL. Based on the workers' competence and commitment to perform their assignments in a safe, secure, and environmentally responsible manner, line managers authorize work to be performed. IWDs were the authorization and approval documents for moderate and high hazard work performed at LANL.

The Board concludes that C-SIC managers did not fully evaluate IWD-C-SIC-0130-04 and the Field Change for compliance with IMP 300 requirements and proper hazard analysis and control identification before authorizing work in Rooms 402, 409, and Alpha Wing.

5 CAUSAL FACTORS

5.1 Direct Cause

Making and using aqua regia outside a functional laboratory hood resulting in workers inhaling acid vapors and other toxic constituents was the direct cause of this accident.

5.2 5.2 Root Cause

5.2.1 Local Root Cause

Chemistry Division management did not ensure that workers recognized the full extent of the hazards associated with making and using aqua regia, did not ensure the workers were trained in LANL work control requirements, and did not ensure workers followed institutional work control practices.

5.2.2 Systemic Root Cause

LANL's ongoing difficulties in ensuring that institutional policies and procedures were implemented in the workplace resulted in deficient worker protection management practices in Chemistry Division.

5.3 Contributing Causes

The real and potential health effects associated with exposure to aqua regia vapors were not recognized by M1, PD1, and PD2.

The lack of unambiguous communication led to confusion among M1, PD1, and PD2 as to where the frits were to be cleaned and what controls were absolutely necessary.

The failure to report the accident deprived LANL management the opportunity to take steps to minimize the severity of the injury.

C Division management did not assure M1, PD1, and PD2 were properly trained to initiate and complete IWDs in accordance with LANL policies and procedures.

C Division's practice of relying on postdocs to develop Integrated Work Documents (IWDs) without ensuring that they were trained in hazard recognition and analysis resulted in the injured postdoc using an IWD that did not establish a comprehensive set of protective measures.

The hazards associated with the work being performed in C Division at the time of the accident had been incorrectly graded. The hazards associated with making and using aqua regia should have been graded "high," but had been graded "moderate." Had the hazard been graded in accordance with LANL guidance, safety and health professionals would have been involved in the hazard identification and work planning process.

Many existing C Division HCPs had not been required to fully analyze the hazards associated with chemical operations because of the previous coverage of these operations under 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories*.

LANL did not train personnel to recognize near misses and other abnormal events, that these events must be reported to management, and that failure to report near misses is considered an unsafe act.

LASO did not manage findings from FR surveillances, assessments, and previous accident investigations in a manner that assured effectiveness of corrective actions in a timely manner.

LASO's informal system for tracking issues arising from surveillance activities and the management of other corrective actions contributed to LASO's ineffective management of corrective actions.

The lack of LASO presence in the field contributed to the unidentified IWD training and implementation weaknesses exhibited by the C Division management and others, which contributed to the inadequacies identified by the Board in the preparation and execution of the IWD-C-SIC-0130-04 and the subsequent field change.

6 CONCLUSIONS AND JUDGEMENTS OF NEED

Judgments of Need (JONs) are the managerial controls and safety measures determined by the Board to be necessary to prevent or minimize the likelihood or severity of a recurrence of this or similar accidents. These JONs are linked directly to the Board's conclusions and causal factors, which are derived from the facts and analyses and form the basis for corrective action plans and which are the responsibility of line management. The following table contains the Board's conclusions, the ISMS Core Functions (CFs) and Guiding Principles (GPs) that support the Board's conclusions, and the associated JONs.

<table>
<tr><th>CONCLUSIONS</th><th>JUDGMENTS OF NEED</th></tr>
<tr><td>SPECIFIC TO THE ACCIDENT</td><td rowspan="7">JON 1: C Division needs to assess their performance to ensure that IWDs thoroughly identify activity-specific chemical hazards, analyze the risks to workers, and ensure that established controls are adequately protective, as outlined in IMP 300, prior to starting work.

JON 2: C Division needs to ensure that IWM-required pre-job briefings are conducted to inform personnel of the hazards of specific activities and the controls necessary to perform a task safely.</td></tr>
<tr><td>The Board concludes that aqua regia vapor concentrations in PD1's and PD2's breathing zones likely exceeded the Short Term Exposure Limits (STEL) and that Immediately Dangerous to Life and Health (IDLH) Limits may have been exceeded. (CF 4)</td></tr>
<tr><td>The Board concludes that an available, identified engineered control (i.e., a functional laboratory hood) was not used. (CF 2)</td></tr>
<tr><td>The Board concludes that M1 and IH1 intended that the Nederman® was to be used solely to vent the dry box. (CF 3)</td></tr>
<tr><td>The Board concludes that there was confusion among M1, PD1, and PD2 as to where the frits were to be cleaned and what controls were absolutely necessary. (CF 3&4)</td></tr>
<tr><td>The Board concludes that PD1 and PD2 were not clearly informed that the purpose of the Nederman® was solely to ventilate the dry box and was not intended to provide ventilation for other activities in Room 402. (CF 3)</td></tr>
<tr><td>The Board concludes that frit cleaning with aqua regia was performed on the benchtop in Room 402 without using the engineered control stated in IWD -C-SIC-0130-04 (i.e., a functional laboratory hood). (CF 4)</td></tr>
</table>

The Board concludes that none of the C-SIC employees who were aware of the aqua regia incident in Room 402 believed that a reportable accident had occurred. (CF 5)	
The Board concludes that the accident was not reported to LANL management as required by LIR 402-130-01.3, *Abnormal Events*. (CF 5)	
The Board concludes that the accident was not reported to LANL management as required by DOE P 450.7, *Department of Energy Environment, Safety and Health (ES&H) Goals*. (CF 5)	
The Board concludes that the failure to report the accident deprived LANL management the opportunity to take steps to minimize the severity of the injury. (CF 5)	
The Board concludes that M1's, PD1's, and PD2's drive to accomplish research activities took priority over housekeeping activities such as frit cleaning, even though the hazard level associated with frit cleaning was graded by PD2 as equivalent to research activities. (GP 4)	
CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO TRAINING	
The Board concludes that the C Division practice of relying on postdocs to develop IWDs without first ensuring that they were trained in hazard recognition and analysis resulted in some IWDs that did not establish a comprehensive set of protective measures. (GP 3)	**JON 3**: C Division management needs to ensure that staff members authorized to develop, review, approve, and implement IWDs receive LANL-required IWM training on how to perform hazard identification, hazard analysis/grading, how to develop hazard controls, and how to prepare complete IWDs.
The Board concludes that even though IMP 300 was in effect at the time that PD2 developed IWD-C-SIC-0130-04, PD2's training records indicated that the required training for IWD Preparers had not been completed. (GP 3)	

The Board concludes that the C-SIC personnel involved with the preparation, review, approval, and Field Change to IWD-C-SIC-0130-04 were not knowledgeable of the application of types of hazard controls (i.e., administrative vs. engineering). (GP 3)	
The Board concludes that M1, PD1 and PD2 were not fully trained or qualified to perform the roles of IWD Preparer or PIC. (GP 3)	
SPECIFIC TO HAZARD GRADING AND ASSESSMENT	
The Board concludes that many existing C Division HCPs were not required to fully analyzed the hazards associated with chemical operations because of the previous coverage of these operations under 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories.* (CF 2)	
The Board concludes that IWD-C-SIC-0130-04 incorrectly graded the hazard associated with making and using aqua regia as a moderate hazard; the hazard grading should have been high hazard in accordance with IMP 300, Hazard Grading Matrix. (CF 3)	
The Board concludes that IWD-C-SIC-0130-04 incorrectly graded the hazard associated with uranium tetrachloride synthesis as a moderate hazard; the hazard grading should have been high hazard in accordance with IMP 300, Hazard Grading Matrix. (CF 3)	

CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO IWD	
The Board concludes that the "Work Task/Step" column described a broad range of chemicals that potentially may be used, but did not identify a specific sequence of work task/steps in a manner that enabled subsequent hazard analysis. (CF 1)	**JON 4:** C Division needs to develop and implement an effective way of tracking individual training records that managers and employees can use to confirm their authorization, qualification, and fitness for duty.

The Board concludes that, as written, the Field Changes for TA-48/RC-1 Room 409 and 407 and TA-48/RC-1/Alpha Wing did not identify the hazards and controls necessary for the tasks identified on the IWD. (CF 2&3)	
The Board concludes that the field change to IWD-C-SIC-0130-04 did not document that a pre-job briefing or operational walk-down was conducted in the manner specified in IMP 300. (CF 4)	
The Board concludes that the Field Changes for TA-48/RC-1 Room 409 and 407 and TA-48/RC-1/Alpha Wing did not identify the hazards and controls necessary for the tasks identified on the IWD. (CF 3)	
The Board concludes that the field change to IWD-C-SIC-0130-04 did not document that a pre-job briefing or operational walk-down was conducted in the manner specified in IMP 300. (CF 4)	
The Board concludes that the pre-job briefing on June 7, 2005 focused on the UCL_4 synthesis and did not clearly communicate to PD1 and PD2 that frit cleaning could not be done in Room 402, as the original IWD-0130-04 stated. (CF 4)	
The Board concludes that although C-SIC employees involved in this accident believed that they understood their roles and responsibilities for generating and managing IWDs, they had not received required training nor were they fully aware of their responsibilities under IMP 300. (GP 3)	
The Board concludes that while PD1 and PD2 were competent to perform their duties as chemists they did not fully understand the hazards associated with making and using aqua regia. (GP 3)	

The Board concludes that C-SIC managers did not fully evaluate IWD-C-SIC-0130-04 and the Field Change for compliance with IMP 300 requirements and proper hazard analysis and control identification before authorizing work in Rooms 402, 409, and Alpha Wing. (GP 7)	
CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO C DIVISION	**JON 5:** C Division needs to ensure that existing IWD's are thoroughly reviewed for compliance with the requirements of IMP 300 Hazard Grading Matrix in order to verify that hazards are properly categorized, appropriately analyzed, and the results are used to identify activity-specific controls. **JON 6:** C Division needs to train personnel to recognize near misses and other abnormal events, that they must be reported to management, and that failure to report near misses is considered an unsafe act.
The Board concludes that C Division management has not been proactive in assuring timely completion of outstanding corrective actions identified in the Management Self-assessment. (GP 1 & CF 5)	
The Board concludes that, while expressing concern about this accident, C Division management has not shown a sense of urgency to ensure that proper work control processes were followed in C Division as demonstrated by failure to assess IMP 300 implementation in August 2005 as planned in the C Division MSA CAP. (GP 1 & CF 5)	
The Board concludes that C Division did not implement the safety and health requirements established in the LANL contract in a manner that ensured workers were protected from serious, recognized workplace hazards, such as aqua regia vapors. (CF 4)	
The Board concludes that many existing C Division HCPs did not fully identify controls for the hazards associated with chemical operations because of the previous coverage of these operations under 29 CFR 1910.1450, *Occupational Exposure to Hazardous Chemicals in Laboratories.* (CF 3)	
The Board concludes that the C Division management did not clearly communicate expectations for reporting near miss events. (CF 5)	

The Board concludes that C Division management did not assure that employees completed training required by IMP 300 for IWD Preparers and PICs prior to authorizing work under IWD-C-SIC-0130-04. (CF 3 & GP 3)	
The Board concludes that without reliable, accurate, and timely training records, C-SIC management would find it difficult to determine which workers are qualified to perform specific tasks. (GP 3)	
The Board concludes that C Division staff members interviewed were generally comfortable voicing safety concerns without fear of retribution, and believed that management would follow up on their concerns. (CF 5)	
CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO LANL	
The Board concludes that the LANL practice of rolling-up safety and health issues across the Laboratory and waiting for the development of Laboratory-wide solutions sometimes results in delays in addressing safety related issues at the activity level. (CF 5)	**JON 7:** LANL needs to take more timely actions to ensure that institutional policies and procedures are effectively implemented in the workplace to correct deficient worker protection management practices previously identified in Chemistry Division. **JON 8:** LANL needs to prioritize resources to focus significant management attention on timely completion of corrective actions for identified deficient safety management practices such as those identified by accident investigations, audits, and assessments. **JON 9:** LANL needs to revise the LIR 402-130-01.3, *Abnormal Events* and associated general employee training to ensure workers report all near miss events that may impact the safety or health of employees so that these events can be evaluated for lessons learned and potential reportability.

CONCLUSIONS	JUDGMENTS OF NEED
The Board concludes that LANL's actions demonstrated investigative readiness and that their activities enabled the Board's conduct of this investigation.	No JON
CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO LASO	
The Board concludes that the change of JON 14 Corrective Action 3 and deliverable removed from NNSA/LASO the responsibility to verify LANL has a robust, rigorous, and credible self-assessment program as required by DOE P 450.5. (CF 5)	**JON 10:** LASO needs to broaden the focus of safety and health oversight activities to cover hazardous LANL activities in a more comprehensive manner as described in DOE/NNSA directives.
The Board concludes that the length of time (57 months) that LASO/LANL took to address the JONs arising from the March 2000 accident is not indicative of organizations with a strong commitment to using feedback from accident experience to drive improvements in safety culture. (CF 5)	**JON 11:** LASO needs to manage findings from FR surveillances, assessments, and previous accident investigations in a manner that assures timely and effective completion and validation of corrective actions.
The Board concludes that LASO's informal system for tracking issues contributed to LASO's ineffective management of corrective actions associated with the Type B CAP that were assigned to NNSA/LASO. (CF 5)	**JON 12:** LASO's needs to develop and implement a formal system for tracking issues arising from surveillance activities and to facilitate the effective management of other corrective actions.
The Board concludes that the reduced LASO oversight and field presence resulted in a lost opportunity for the LASO to observe and assess the Laboratory's implementation and effectiveness of the Integrated Work Management processes including development and implementation of the Integrated Work Documents. (CF 5)	**JON 13:** LASO needs to increase the level of oversight and field presence in C Division facilities and activities in order to observe and assess the contractor's implementation and effectiveness of the Integrated Work Management process.
The Board concludes that the lack of LASO presence in Technical Area 48 allowed the C-Division IWD training and implementation weaknesses identified by the Board to go undetected. (CF 5)	

The Board concludes that LASO was aware of LANL's ongoing poor performance with regard to ISMS implementation and took action in accordance with the terms and conditions of the contract. (CF 5)	
CONCLUSIONS	JUDGMENTS OF NEED
SPECIFIC TO NNSA	
The Board concludes that NNSA-approved site-specific ES&H goals were not established, LASO has received no guidance from NNSA regarding the development of site-specific ES&H performance goals, and no quarterly reporting to NNSA is occurring for site-specific ES&H goals.	**JON 14:** NNSA/LASO needs to establish LANL site-specific ES&H goals and measures and LASO needs to report on those goals and measures as required by DOE P 450.7, *Department of Energy Environment, Safety, and Health (ES&H) Goals*.
The Board concludes that NNSA recognized continuing issues related to the effective implementation of work controls requirements (ISMS) and coordinated appropriate action with the Office of Enforcement.	No JON

7.0 BOARD SIGNATURES

Don W. Harvey, CIH, CSP
DOE Board Chairperson
U.S. Department of Energy
National Nuclear Security Administration
HQ/FORS

Marcus Hayes, CSM
DOE Board Member -Trained Accident Investigator
U.S. Department of Energy
National Nuclear Security Administration
Albuquerque Service Center

Kenneth Meyers, COHST
DOE Board Member
U.S. Department of Energy
National Nuclear Security Administration
Pantex Site Office

Keith Warwick, PE
DOE Board Member
U.S. Department of Energy
National Nuclear Security Administration
Livermore Site Office

William C. McQuiston
DOE Board Member
U.S. Department of Energy
Idaho Operations Office

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LIST OF BOARD MEMBERS, ADVISORS, AND STAFF

Board Members

Chairperson	Don W. Harvey, CIH, CSP, Senior Occupational Safety and Health Advisor, NNSA HQ (NA-1)
Member	Marcus Hayes, CSM, Occupational Safety and Health Manager, National Nuclear Security Administration Service Center
Member	Kenneth Meyers, COHST, Industrial Hygienist, National Nuclear Security Administration, Pantex Site Office
Member	Keith Warwick, PE, Facility Representative, National Nuclear Security Administration, Livermore Site Office
Member	William C. McQuiston, Facility Engineer, Department of Energy, Idaho Operations Office (added after appointment memorandum with Mr. Wilmot's approval)
Technical Liaison	Gary Whitney, CIH, Industrial Hygienist, HSR-5, LANL
Administrative Support	Cynthia A. Cordova-Rivera, Administrative Analyst, National Nuclear Security Administration Service Center, CE2 Corporation
Transcriptionist	Teresa E, DuBois, Trambley's Court Reporting

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APPENDIX A - APPOINTMENT OF TYPE B ACCIDENT INVESTIGATION BOARD

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UNITED STATES GOVERNMENT **DEPARTMENT OF ENERGY**

memorandum

National Nuclear Security Administration
Los Alamos Site Office
Los Alamos, New Mexico 87544

DATE: AUG 15 2005
REPLY TO ATTN OF: OFO:8KK-024
SUBJECT: Type B Investigation – Over Exposure to Hazardous Chemical Vapors at TA-48-1-402

TO: Don Harvey, CIH, CSP, Board Chairperson, NA-1. HQ/FORS

I hereby establish a Type B Accident Investigation Board to investigate the incident that was discovered at the Los Alamos National Laboratory's TA-48-1-402 on July 16, 2005. I have determined that it meets the requirements established in DOE Order 225.1A, "Accident Investigations" dated November 26,1997, for a Type B Accident Investigation Board.

I appoint you as the Board Chairperson. The team will consist of:

Board Members:
Marcus Hayes, CSM, NNSA Service Center
Kenneth Meyers, NNSA Pantex Site Office
Keith Warwick, NNSA Livermore Site Office

Trained Investigator:
Marcus Hayes, CSM, NNSA Service Center

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

The Board will be chartered for a time-period of August 15, 2005, to September 30, 2005. In the event that the Board cannot conclude its investigation by September 30, 2005, the investigation will be extended until the Board's investigation is complete.

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

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

This report should be provided to me for acceptance by September 30, 2005. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

Edwin L. Wilmot
Manager

cc:
E. Morrow, NA-1, HQ/FORS
J. McConnell, NA-1, HQ/FORS
T. D'Agostino, NA-10, HQ/FORS
D. Minnema, NA-1, HQ/GTN
D. Harvey, NA-1, HQ/FORS
J. Chavez-Wilcynski, OOM, LASO
G. Schlapper, SSA, LASO
R. Corman, OC, LASO
C. Crooks, BA, LASO
A. Lovato, BA, LASO
K. Keilholtz, AMFO, LASO
J. Pugh, OFO, LASO
E. Christie OFO, LASO
C. Keilers, DNFSB, LASO
D. Cobb, DIR, LANL, MS-A100
R. Lemons, ADSR, LANL, MS-A127
C. Mangeng, ADTS, LANL, MS-A104
J. Angelo, PS-DO, LANL, MS-C347
P. Follansbee, MST-DO, LANL, MS-G754
V. Majidi, C-DO, LANL, MS-J515
W. Wadt, PCO, LANL, MS-M722
E. Christe, OFO, LASO

APPENDIX B - BARRIER ANALYSIS

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BARRIER ANALYSIS

Barrier analysis is based on the premise that hazards are associated with all tasks. For an accident to occur, there must be a hazard that comes into contact with a target because the barriers or controls were not in place, not used, or failed. A hazard is the potential for unwanted energy flow to result in an accident or other adverse consequence. A target is a person or object that a hazard may damage, injure, or fatally harm. A barrier is any means used to control, prevent, or impede the hazard from reaching the target, thereby reducing the severity if the resultant accident or the adverse consequence. The results of the barrier analysis are contained in the following table.

HAZARD: Aqua Regia Vapors		TARGET: PD1 and PD2	
What were the barriers?	How did the barrier perform?	Why did the barrier fail?	How did the performance of the barrier affect the accident?
Respiratory protection for acid vapors	Not provided	Not Used	Not applicable
Functional laboratory fume hood	Hood in Room 402 was not functional	Ventilation fan motor was out – hood was sealed shut	Hood not available to protect PD1 and PD2 from aqua regia vapors
PPE used: Lab coats, gloves, safety glasses with side shields	Did not provide respiratory protection	PPE was not selected for respiratory protection	Did not prevent PD1 from inhaling acid vapors
Make-up air to Room 402	Provided little dissipation of acid vapors as they evolved	Not intended to dissipate airborne hazards	May have increased concentration of acid vapors in the PD1's breathing zones
Nederman dry box exhaust	Did not exhaust aqua regia vapors from Room 402 atmosphere	Was not intended to provide task exhaust for frit cleaning	Gave false sense of protection to PD1 and PD2
Pre-Job briefing on June 7 clearly communicates hazards associated with tasks and establishes effective controls	Focused more on chemical operations than on safety of frit cleaning	Focus was on finding locations to perform UCL_4 synthesis and frit cleaning using aqua regia was not discussed	PD1 believed they had been instructed to clean frits in Room 402

HAZARD: Aqua Regia Vapors		TARGET: PD1 and PD2	
What were the barriers?	How did the barrier perform?	Why did the barrier fail?	How did the performance of the barrier affect the accident?
IWD process is used to identify hazards and implement controls	Specified control (hood in Room 402) was not functional – Field change to IWD C-SIC-0130-04 did not include use of aqua regia in Room 409 – IWD did not prevent use of aqua regia outside of a functional hood	Efforts made to generate a field change to IWD C-SIC-0130-04 did not include frit cleaning in Room 409	PD1 believed they were only authorized to clean frits in Room 402 – PD2 believed there was sufficient air movement in Room 402 to control the acid vapor hazard
Work performed in accordance with IWD that refers to using AR in Room 402 in a functional hood	Frit cleaning using aqua regia in Room 409 was not included in field change to IWD C-SIC-0130-04	Frit cleaning was attempted without proper hazard controls	PD1 and PD2 attempted frit cleaning using aqua regia in Room 402 outside a functional hood
IWD prepared by fully trained personnel identifies task-specific hazards and controls	Field change to IWD C-SIC-0130-04 did not include frit cleaning using aqua regia	Preparer failed to identify frit cleaning in IWD for Room 409	PD1 believed they were only authorized to clean frits in Room 402 – PD2 believed there was sufficient air movement in Room 402 to control the acid vapor hazard
Chemical hazards training ensures that workers recognize task-specific hazards and effective controls	PD1's and PD2's knowledge of aqua regia underestimated hazards of constituents of acid vapor	PD1 and PD2 did not anticipate the magnitude of the respiratory hazard	PD1 and PD2 attempted frit cleaning using aqua regia outside of a functional hood
PDs exercise stop work authority	Not exercised	PD1 and PD2 did not anticipate the magnitude of the respiratory hazard	Preparation of aqua regia outside of a functional hood exposed PD1 and PD2 to acid vapor

HAZARD: Aqua Regia Vapors		TARGET: PD1 and PD2	
What were the barriers?	How did the barrier perform?	Why did the barrier fail?	How did the performance of the barrier affect the accident?
Prompt reporting of acid vapor exposure to C-SIC management minimizes severity of consequences	Acid vapor exposure not reported to C-SIC management	When M1 questioned PD1 and PD2 about the frit cleaning both believed they did not need to go to HSR-2 (occupational medicine)	PD1 suffered a delayed reaction to the constituents of the aqua regia vapor that resulted in 6 days hospitalization
Prompt reaction by safety and health professionals informed of the accident minimizes severity of consequences	Acid vapor exposure not reported to C-SIC management, HSR-5, or HSR-8	Although PD1's husband mentioned the accident to a LANL industrial hygienist in another division, the industrial hygienist did not ensure that LANL management was informed of the accident	PD1 suffered a delayed reaction to the constituents of the aqua regia vapor that resulted in 6 days hospitalization

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APPENDIX C – ACCIDENT RECONSTRUCTION

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ACCIDENT RECONSTRUCTION: RECREATING EVENT CONDITIONS IN ROOM 402

A DOE industrial hygienist on the Board and the LANL technical liaison (TL) worked with PD2 to set up Room 402 to recreate as closely as possible the conditions in the room when the aqua regia was used (see Figure 1). A 26"x18''x2" metal pan of the same type used during the event was placed as it was at the time of the accident, next to the convection oven on the east lab bench top. Three 800 ml beakers were placed in the pan as they were during the event. One represented the beaker used to mix the aqua regia (beaker A) and two containing the Büchner funnels that were to be cleaned (beakers B and C). Two plastic bottles were placed in the pan to represent the acid bottles. No actual acids were used during the re-creation.

Evaporative coolers (WisperCool® Model P300, AdobeAir, Inc., Phoenix, AZ) were filled with water and placed in the same locations as during the event. Coolers were started before airflow measurements were made to allow them to reach normal operating conditions.

The dry box in Room 402 contained materials that are sensitive to oxygen and/or water. It required a constant, low flow of dry nitrogen and an active catalyst bed to maintain acceptable conditions. The dry box was normally exhausted through a metal flex hose leading to a copper pipe (approximately 1.25" diameter) that was routed directly to hood 9420. While the exhaust fan for the hood was down for repairs, a temporary exhaust system was set up using a portable ventilation system (Model 61268, Nederman, Inc., Westland, MI, serial #662, LANL property #694721). Nederman® systems are normally used to ventilate welding operations. To use the Nederman® to ventilate the dry box, the exhaust vent line from the dry box was routed into the hood inlet of the ventilator. The exhaust from the ventilator was routed with a 10' section of 6" aluminum flex duct through an opening in the Plexiglas window next to the air conditioner on the east side of the room.

To recreate room conditions, the Nederman® was set in place and operated as it was during the accident. An exception was that instead of venting the actual dry box exhaust into the system, a piece of metal flex hose was inserted into the hood opening of the Nederman® in the same manner as the dry box vent had been routed during the event. The Nederman® was rated at 530 cfm when used for welding ventilation. With the additional ten feet of flex duct to route the exhaust through the window, however, air flow would be expected to be significantly lower.

The fan exhausting the hoods in the room was shut down at approximately 2:00 pm on August 31, 2005. Affected hood sashes, including the hoods in Room 402, were closed and sealed with plastic and tape. At this point, Room 402 was essentially under the same conditions as on June 7, 2005, with the exception of temperature. Reports indicated that the temperature in Room 402 was between 90° and 95° F on the day of the accident. During the recreation, the temperature ranged from 80° to 82° F. The portable ventilation system and the evaporative coolers generated a constant “fan” noise that was always audible, but not loud enough to interfere with voice communication.

Measurements of room air velocity with anemometer.

Air velocity measurements were made using a with TSI VelociCalc thermal anemometer at the lab bench top where the aqua regia was used and at the hood opening of the Nederman® (see Table C-1 and Figures C-1 and C-2). Air velocity measurements were made with the doors to the room closed and then with the doors to the room open. The doors to the room were open at the time of the accident to help cool the room during the hot weather.

The LANL TL stood upright at point A facing the work area. Air velocity measurements were taken 6” above the tops of the beakers sitting in the pan, 14” above the tops of the beakers (approximate worker breathing zone), and at the gap between the edge of the bench top and the LANL TL. Air in the room was very still. The LANL TL had to hold his breath and stand still to get a stable reading with the anemometer. With the room doors closed, air velocities above the bench top were barely measurable, between zero and one fpm. Opening the room doors increased air velocities to only 2 to 3 fpm. Having the room doors open allowed an exhaust pathway for the supply air from the ceiling vents.

Air velocity measurements were taken in the plane of the hood opening of the Nederman® in order to calculate a rough estimate its flow rate. See Figure C-2.
Air velocity at points 1, 3, 4, 5, and 6 averaged 512 fpm. The 10” by 12” oval hood opening had an area of 0.66 ft^2. The Nederman® would have provided about 340 cfm exhaust ventilation from the room. With a floor area of 672 ft^2 and a 12 ft ceiling, Room 402 has a volume of 8064 ft^3. The Nederman® provided approximately 2.5 air changes per hour in the room.

Observations of room air currents using smoke tubes.

Air currents in Room 402 were evaluated using smoke tubes (Dräger air current tubes; part number CH25301). Attempts were made to photograph the smoke as it followed the air currents in the room. This had only limited success, however, as the white smoke was difficult to photograph against the predominately light colored features of the room. The digital photographs did not provide a good sense of the distance or depth of the smoke cloud. Observers in the room, however, were able to observe the smoke as it followed the patterns of the air currents in the room. Observers were also able to detect the smell of dilute smoke as it entered their breathing zones. Narratives of air current patterns observed in the room by the LANL TL are provided below. Observations are indicated for each of the reference points indicated on the room diagram (Figure C-1).

Point A:

Point A represents the position of a worker mixing the aqua regia and pouring it into the Büchner funnels that were being cleaned. The LANL TL performing the smoke tests stood upright at point A facing the work area and released smoke at the top of the beaker that would have been used to mix the aqua regia (beaker A). The released smoke traveled slowly 2 to 3 feet to the right as it began to rise. It initially appeared that the air currents were traveling away from a worker standing at point A. However, when the smoke reached approximately 7 to 8 feet height above the floor it curved back to the left and began to descend down toward the work area and into the breathing zone of the LANL TL. The LANL TL could smell and taste the irritant smoke as it descended. The smoke tended to stay in a plane parallel to the wall, with only minimal diffusion toward the center of the room. Repeated smoke releases consistently indicated the same general flow of air at point A in the room. Supply air to the room from ceiling vents and heat from the convection oven on the bench top next to the work area are likely to have created conditions in the room forming a stable eddy current centered slightly to the right of the work area in a plane parallel to the wall (see Figures C-5, C-6, and C-7).

The LANL TL also released smoke at the top of the beakers while holding beaker A in his right hand above beakers B and C and leaning slightly forward to be better able to observe the Büchner funnels in beakers B and C. A similar posture was likely to have been taken by a worker when the aqua regia had been mixed and the Büchner funnels were being filled.

With the LANL TL in this position a “chimney effect” was observed. When released at the top of beaker A, the stream of smoke could be observed traveling up along the surface of the LANL TL’s right arm and into his breathing zone. When released at the top of beakers B and C, the stream of smoke would sometimes move toward the LANL TL and travel up along his chest and into his breathing zone. The LANL TL could smell and taste the smoke very shortly after release. The concentration of the irritant smoke at some points in these tests was strong enough to cause the LANL TL to pull back from the work area. Rather than travel to the right and enter the eddy current, when the LANL TL took certain postures the released smoke would pass through the breathing zone before being re-circulated to the work area by the eddy current. (see Figures C-8 & C-9)

Points B & C:

Points B and C represent likely positions of a worker observing the mixing of the aqua regia. There was no clearly defined airflow pattern in this region of the room. Smoke released at points B and C tended to diffuse, rise slightly, and move slowly in a southern direction toward the center of the room. Smoke released at the sink east of point B diffused less and moved in a more defined pattern to the south, parallel to the wall. It appeared to enter the eddy current noted at point A.

Point D:

When the LANL TL stood at point D and extended his arm toward the door, the released smoke clearly traveled in a well-defined stream out of the open door. With the hoods shut down, the open doors provided a passive exhaust pathway for the supply air that was entering the room through the ceiling vents.

When the LANL TL stood at point D and extended his arm toward the center of the room, the released smoke tended to diffuse and move in a less defined pattern. The diffused smoke cloud moved slowly in the general direction of the door.

Point E:

When the LANL TL stood at point E and extended his arm toward the door, the released smoke moved slowly in the general direction of the door. Release of smoke at point E in the direction of the dry box resulted in a highly variable pattern. In most cases the smoke would diffuse and rise then move slowly to the right or left. No clear airflow pattern could be detected in this area of the room.

The evaporative cooler sitting on the floor near point E did not appear to significantly effect the movement of smoke released at breathing zone level. With the cooler fan set on high, the LANL TL could just perceive air flow with his hand one foot in front of the cooler. Airflow from the cooler is distributed at a wide angle and is at floor level.

Discussion:

Airflow was very low under the conditions re-created in Room 402. The Nederman® portable ventilation system used to vent the dry box and the passive flow of air into the hallway provided some general dilution ventilation for the room. However, this was not adequate for, nor was it ever intended for the use of aqua regia on a lab bench top.
The observed eddy current would have concentrated and retained vapors and gasses released from the aqua regia in the area around point A. The "chimney effect" observed could expose a worker at point A to highly concentrated vapors and gasses. Due to the minimal air flow in the room, a much lower exposure would be expected for a worker standing at points B or C than for the worker making and using the aqua regia at point A.

The observed smoke movements at point A would indicate airflow that was at a higher velocity than that measured with the thermal anemometer. This could be due to inaccuracies in anemometer readings at very low air velocities and/or to the subjective nature of humans estimating air velocity by observing smoke movement. Measurements and observations in Room 402 were completed and the hoods returned to service at approximately 4:00 pm on August 31, 2005.

Table C-1, Air flow measurements made in TA-48-RC1-402 on 8/31/05

Temperature: 3:38pm 80° F (Measured with thermometer on top of dry box.)
5:40pm 82° F

Location	Room Doors Closed standard fpm	Room Doors Open standard fpm
Worker at point A; 6" above beaker at pan; Nederman® ventilator off	0	3
Worker at point A; 6" above beaker at pan; Nederman® ventilator on (on for remainder of tests).	1	2
Worker at point A; 14" above beaker at pan; worker breathing zone	1	2 to 3
Worker at point A; at bench top level (36"), between worker and edge of bench top.	1	1
Observer at point B; observer breathing zone.	1 to 2	1 to 2
Nederman® hood point 1a: 6" out, at center of hood.	110	160
Nederman® hood point 1b: Plane of hood opening, at center of hood	440	440
Nederman® hood point 2: Plane of hood opening, by flex hose.	700	680
Nederman® hood point 3: Plane of hood opening, at top 1/4 of hood.	400	380
Nederman® hood point 4: Plane of hood opening, at bottom 1/4 of hood.	770	760
Nederman® hood point 5: Plane of hood opening, at right 1/4 of hood.	540	540
Nederman® hood point 6: Plane of hood opening, at left 1/4 of hood.	450	440
Air velocity measured with TSI VelociCalc® Plus air velocity meter, Model: 8385A; Serial Number: 99040056; HSR-5 Equipment Number: 805; Calibration Due Date: 10/29/05.		

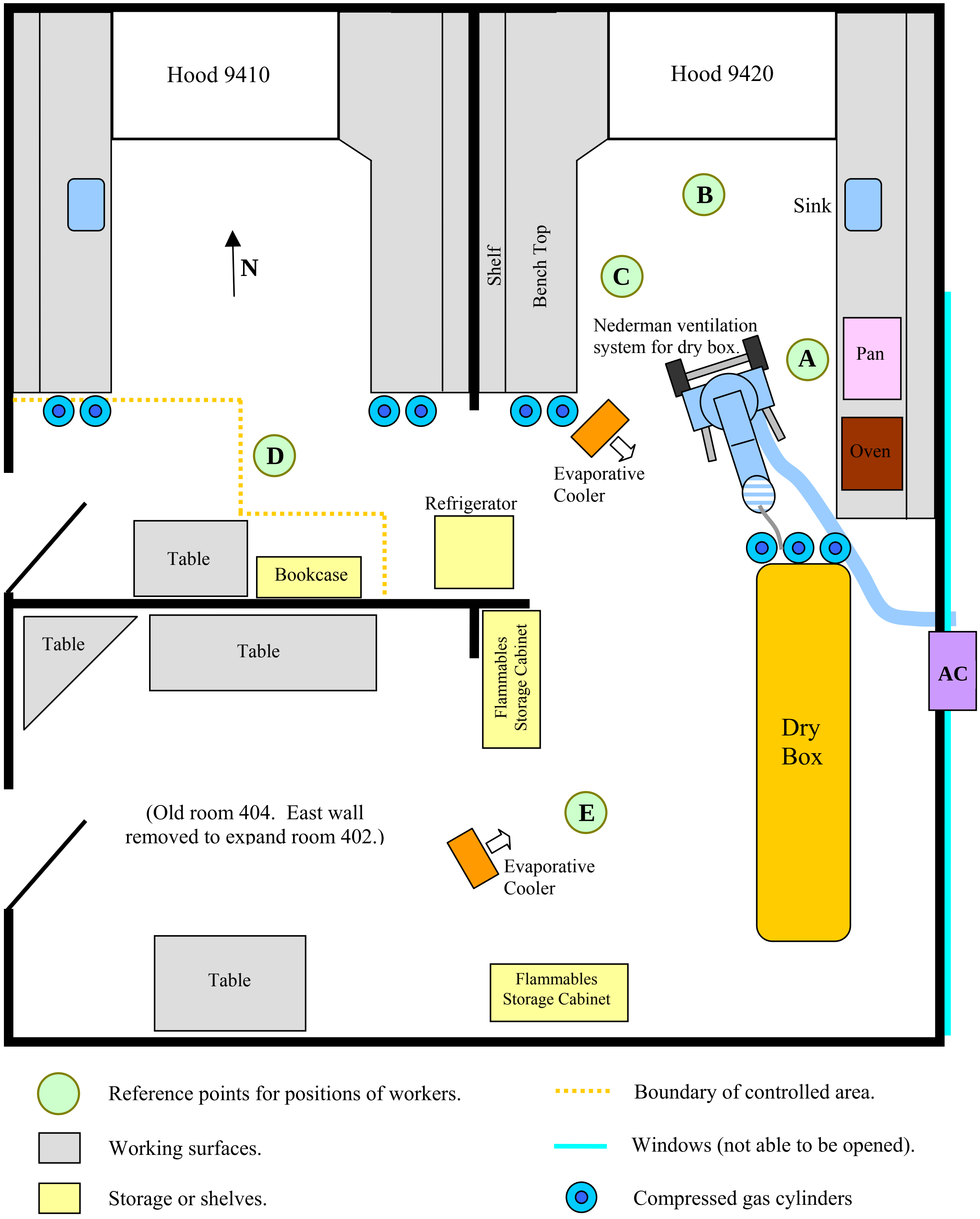
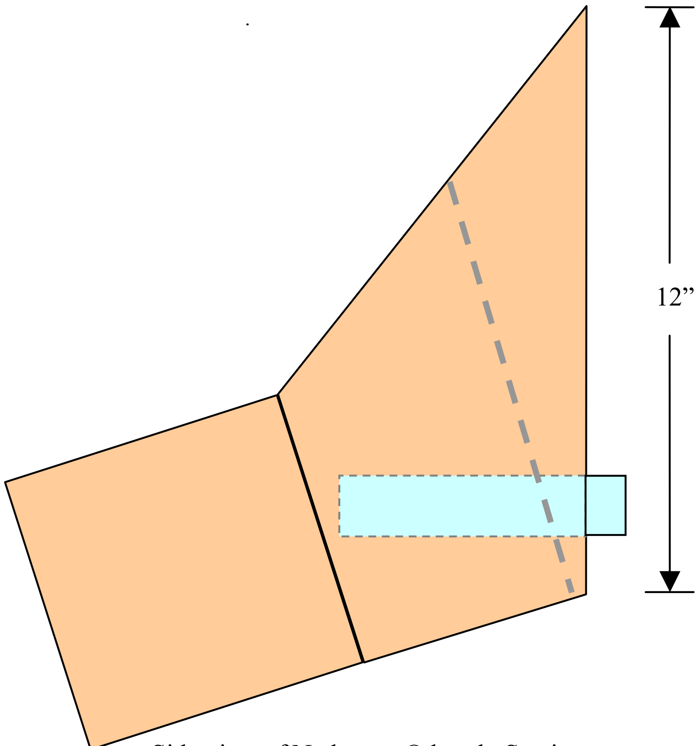
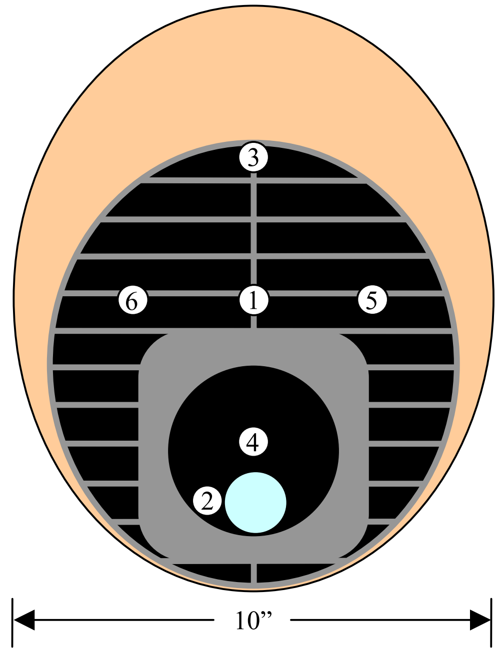


Figure C-1, Diagram of TA-48-RC1-402



Side view of Nederman® hood. Section of 1.25” diameter metal flex hose that vented the dry box is shown in light blue.



Opening of Nederman® hood showing locations of air velocity measurement points in the plane of the hood opening.

Figure C-2, Diagram of hood on Nederman® portable ventilation system.

Figure C-3 The laboratory bench in room 402 during normal conditions when the hoods were operational.

Figure C-4 The laboratory bench and surrounding area in room 402 as it was during the event and when the hoods were not operational.

Figure C-5 The Technical Liaison performing the smoke tests stood upright at point A (see Figure C-1) and released smoke at the top of the beaker that would have been used to mix the aqua regia. The released smoke traveled slowly two to three feet to the right of the IH as it began to rise steeply. It initially appeared that the air currents were traveling away from a worker standing at point A. However, when the smoke reached approximately seven to eight feet height above the floor it curved back to the left and began to descend down toward the work area and into the breathing zone of the Technical Liaison. The Technical Liaison could smell and taste the irritant smoke as it descended. The smoke tended to stay in a plane parallel to the wall, with only minimal diffusion toward the center of the room. This apparent eddy current in the air flow patterns at the bench top was stable. Repeated smoke tests yielded similar results.

Figure C-6 Smoke entrained in the eddy current descending back down into the breathing zone of the Technical Liaison.

Figure C-7 The laboratory bench and surrounding area in room 402. Superimposed arrows show the eddy current in the air flow pattern observed during using smoke tubes.

Figure C-8 The Technical Liaison releasing smoke at the top of the beakers containing Büchner funnels (“frits”) while holding a beaker in his right and leaning slightly forward to be better able to observe the frits. A similar posture was likely to have been taken by a worker during the event. With the Technical Liaison in this position a “chimney effect” was observed. Smoke released at the top of the beakers could be observed traveling up along the surface of the Technical Liaison’s right arm and/or along his chest and into his breathing zone.

Figure C-9 The concentration of the irritant smoke at some points during the smoke tests was strong enough to cause the Technical Liaison to pull back from the work area. When the Technical Liaison took certain postures likely to have been taken by workers, the released smoke would pass through the breathing zone before being re-circulated to the work area by the eddy current.

APPENDIX D – ACID VAPOR EXPOSURE ASSESSMENT

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Estimation of Worker Exposures While Working With Aqua Regia

Reactants and products that may present exposure hazards to workers using aqua regia were identified from industrial hygiene references, resources available on the internet, and material safety data sheets (MSDSs). These compounds are listed in Table 1. Exposure limits from the American Conference of Governmental Industrial Hygienists (ACGIH) and the Occupational Safety and Health Administration (OSHA) are listed for each compound. Exposure concentrations, determined by the National Institute of Occupational Safety and Health (NIOSH) as being immediately dangerous to life or health (IDLH), are also listed.

Table D-1 Compounds of exposure concern for work with aqua regia.

Compound	MW	ACGIH TLV	ACGIH STEL	OSHA PEL	NIOSH IDLH	LC_{50}, ppm
Reactants						
Hydrochloric Acid, HCl (37% Hydrogen Chloride)	36.46		2 ppm (ceiling)	5 ppm (ceiling)	50 ppm	3124 (30 min, rats)
Nitric Acid, HNO_3 70%	63.01	2 ppm	4 ppm	2 ppm	25 ppm	334 (30 min, rats)
Products						
Chlorine, Cl_2	71	0.5 ppm	1 ppm	1 ppm (ceiling)	10 ppm	293 (1 hr, rats)
Nitrosyl Chloride, NOCl	65.47	not established	not established	not established	not established	35 (1 hr, species*)
Nitrogen Dioxide, NO_2	46	3 ppm	5 ppm	5 ppm (ceiling)	20 ppm	115 (1 hr, rats)
Nitric Oxide, NO	30	25 ppm		25 ppm	100 ppm	1068 (1 duration*, rats)

***** Unspecified in the available literature.
Note: Nitric oxide will oxidize in air to produce nitrogen dioxide (per MSDS).

A number of assumptions were required to estimate the airborne exposures to reactants and products of aqua regia. The calculations in the sections below ignore both the solubility of reaction product gasses in the aqua regia and other secondary reactions that might occur. It is assumed that the evolved gasses from the aqua regia were evenly dispersed in a 6 m^3 volume of air surrounding the worker. This volume was selected based on the observations of air flow patterns in the work area and professional judgment.

Due to the complexity of the aqua regia reactions, the assumptions made, and a number of unknown factors, the estimates of exposure levels are provided with the understanding that they are the best available given the limited information on hand. Actual worker exposure could be significantly higher due to the minimal air movement in the work area and the closeness of the worker to the source. Actual worker exposure could be lower due to solubility of reaction products in aqua regia or the loss of products due to secondary reactions.

Estimation of Exposure to Hydrogen Chloride

Hydrochloric acid is volatile and will release hydrogen chloride to the atmosphere. The National Oceanic and Atmospheric Administration (NOAA) developed a calculator to estimate the evaporation rate of hydrochloric acid and other hazardous materials. The Evaporation Calculator program[1] uses acid concentration, surface area, temperature, and wind speed to calculate the rate of evaporation of hydrogen chloride from a pool of hydrochloric acid. The Evaporation Calculator program is intended for outdoor spills of non-reacting pure solutions. The use of this program here provides a "best available estimate" of the HCl that may have evaporated from the aqua regia. The NOAA Evaporation Calculator will also calculate evaporation rates for nitric acid. However, the conditions in this situation are outside of the program's operating parameters for nitric acid. Airborne exposure to nitric acid is believed to be minimal under event conditions.

Evaporation rates were calculated for two temperature conditions. The first was the minimum ambient temperatures reported by workers, 32° C (90° F). The second was 55° C; this is assuming a temperature elevation due to the heat of reaction. The actual temperature of the aqua regia is not known. Anecdotal information from chemists experienced with mixing and using aqua regia indicates that 50° to 60° C is a reasonable estimate for the temperature of a newly mixed beaker of aqua regia.

It was assumed that the surface area was a "puddle" of hydrochloric acid 10 cm by 15 cm. This is believed to be a reasonable estimate for the surface area of the beaker when mixing or pouring and allowed for some material on the sides of the beaker. "Wind speed" was the average 2.5 fpm measured at the work area. The concentration of the hydrochloric acid was entered as 28% after allowing for dilution by the nitric acid.

The Evaporation Calculator program generated a rate of evaporation for the hydrogen chloride in kilograms per minute. A spreadsheet was used to calculate the number of moles of hydrogen chloride emitted by the aqua regia at given times. The resulting concentration was calculated assuming the hydrogen chloride was dispersed in an air volume of 6 m^3 around the source and worker. See Table 2 for results. Actual worker exposures may have been higher due to the limited air movement in the room and the short distance between the source and the worker's breathing zone.

Table D-2 Estimates of hydrogen chloride concentration after mixing aqua regia.

Time After Mixing Acids (min)	HCl, ppm	
	Aqua Regia at 32° C (90° F)	Aqua Regia at 55° C (131° F)
1	0.7	2.7
5	3.3	13
10	6.6	27
15	9.9	40

The estimates assuming the aqua regia to be at 55° C are considered to be more realistic than those assuming it to be at room temperature. With the aqua regia at 55° C, the ACGIH ceiling limit of 2 ppm for hydrogen chloride would have been reached almost immediately. Even if it is assumed that the aqua regia remains at room temperature, the ceiling limit for hydrogen chloride would likely have been exceeded after only 5 minutes. It is almost certain that workers were exposed to hydrogen chloride at levels above established exposure limits.

Estimation of Exposure to Aqua Regia Products

Some chemical reactions of importance for evaluating exposures to aqua regia products:

1) $HNO_3 + 3HCl \rightarrow NOCl + Cl_2 + 2H_2O$

2) $2NOCl \rightarrow 2NO + Cl_2$

3) $2NO + O2 \rightarrow 2NO_2$

4) HNO_3 + (metals and compounds) → NO_2 + (metals and compounds)$^+$ + H_2O

Reaction 1 is the principle aqua regia reaction.
Reaction 2 is the breakdown of nitrosyl chloride.
Reaction 3 is the oxidation of nitric oxide in the air.
Reaction 4 is the reaction of nitric acid and contaminates on the glassware.

This simplified list of equations ignores the solubility of reaction product gasses in the aqua regia and other secondary reactions that might occur. The actual chemistry appears to be rather complex and not well studied. No specific usable information was available on reaction rates. Due to the lack of data on the kinetics of the reaction, an exposure estimate based on evolution of products over time could not be made. Rather, an exposure estimate was attempted based on the percent of nitric acid that may have reacted and generated product gasses for the duration of the aqua regia use.

Based on formula 1), one mole of nitric acid will produce one mole of NOCl and one mole of Cl_2. Reaction 2) indicates that some of the NOCl may breakdown to produce NO and additional Cl_2. Reactions 3) and 4) may produce NO_2. The amount of each nitrogen compound produced by the aqua regia reactions cannot be estimated. However, it is known that one mole of nitric acid will produce one mole of the nitrogen containing products. These products have varying exposure limits (no established exposure limit for NOCl), but similar health effects. It seems reasonable to use the concentration of the sum of these nitrogen containing products when evaluating potential exposures.

A spreadsheet was used calculate the number of moles of nitrogen containing products and chlorine expected to have evolved from the aqua regia. These calculations were based on varying percentages of the nitric acid that might have reacted during the period of use. It was assumed that the aqua regia was made using 100 ml of 70% nitric acid and that the reaction products were dispersed in an air volume of 6 m^3 around the source and worker. See Table 3 for results.

Table D-3 Estimates of chlorine and nitrogen product concentrations after mixing and use of aqua regia. Based on percent HNO_3 reacting and assuming NOCl is stable.

Percent Nitric Acid Reacting	Chlorine Concentration, ppm	Nitrogen Product Concentration, ppm	Total Volume Gasses Evolved, ml
0.05	4.5	4.5	53
0.1	8.9	8.9	107
0.5	45	45	535
1.0	89	89	1069

The actual percentage of the nitric acid that reacted cannot be determined. However, the data in Table 3 indicate that only a very small fraction of the nitric acid would have had to react to produce chlorine and nitrogen products at levels of worker exposure concern. It is reasonable to assume that significant amounts of aqua regia products were available for release into the air.

It has been noted by chemists experienced with aqua regia that there are visible red or brown fumes/gasses evolving from the solution when it is mixed, but that there is no visible bubbling or boiling. If the period of use for the aqua regia was 10 minutes, the rate of evolution of gasses for the worst case in Table 3 would be about 110 ml per minute. It would seem reasonable that this amount of gas could be evolved from the aqua regia with out visible bubbles. Also, because of the solubility of Cl_2 and NOCl, a much higher percentage of the nitric acid could have reacted to form aqua regia products that remained in solution, but were readily available for release to the air.

Toxicology data available in MSDSs and other sources would indicate that NOCl is more toxic than NO_2. NO is less toxic then NO_2 but can be converted to NO_2 in the air (reaction 3). Considering the lack of exposure limits for NOCl and the fact that the relative proportions of the nitrogen products cannot be determined, it would seem reasonable to use the exposure limits for NO_2 as a guideline limit for the sum of the nitrogen products generated by the aqua regia. Using the exposure limits for NO_2 as a guideline, it is likely that the OSHA ceiling exposure limit of 5 ppm would have been exceeded. The IDLH level of 20 ppm may have been exceeded

The actual airborne chlorine concentration could have been significantly different from the calculated concentrations shown in Table 3. If the nitrosyl chloride broke down, the concentration of chlorine could be increased by as much as 50%. Conversely, chlorine may be soluble enough in aqua regia (8.6 g/liter solubility in water) to limit the evolution of chlorine gas; significantly reducing airborne exposure. If the chlorine from the reaction is entering the air in the work area, the OSHA ceiling exposure limit of 1 ppm limit would likely have been exceeded. The IDLH level of 10 ppm may have been exceeded.

Reference

National Oceanic and Atmospheric Administration (NOAA) Evaporation Calculator, (http://response.restoration.noaa.gov/cameo/evapcalc/evap.html#).

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APPENDIX E – EVENTS AND CAUSAL FACTOR CHART

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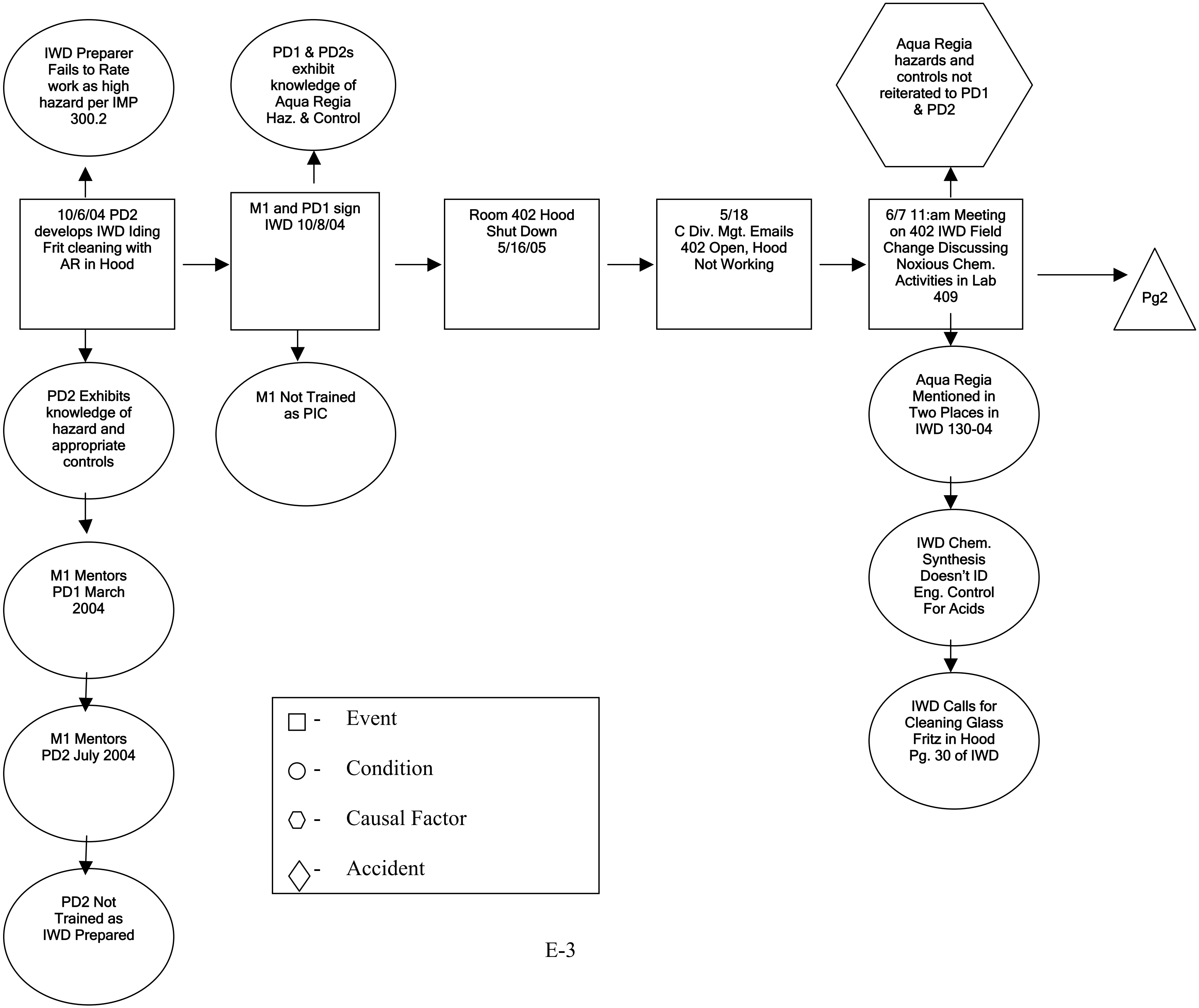
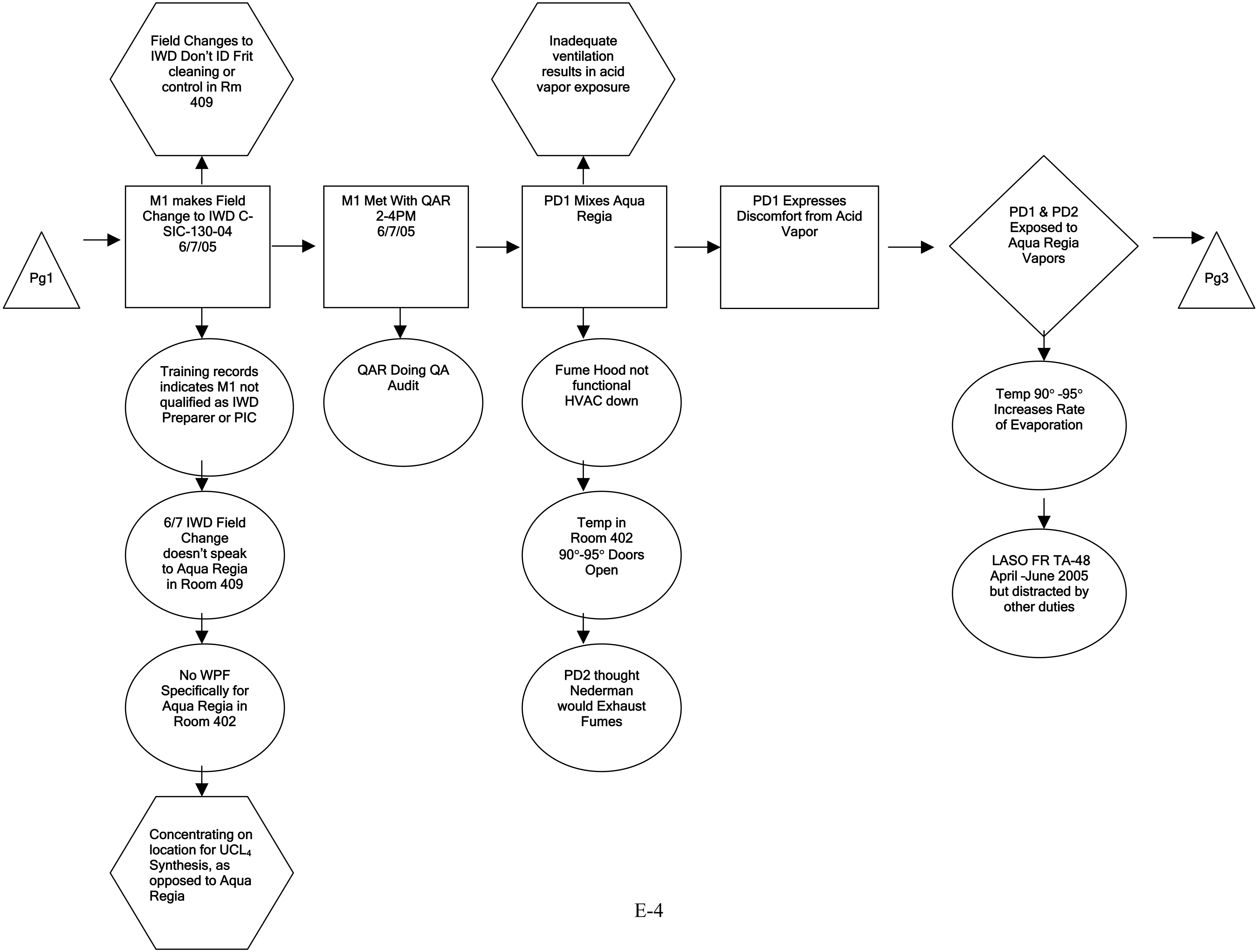
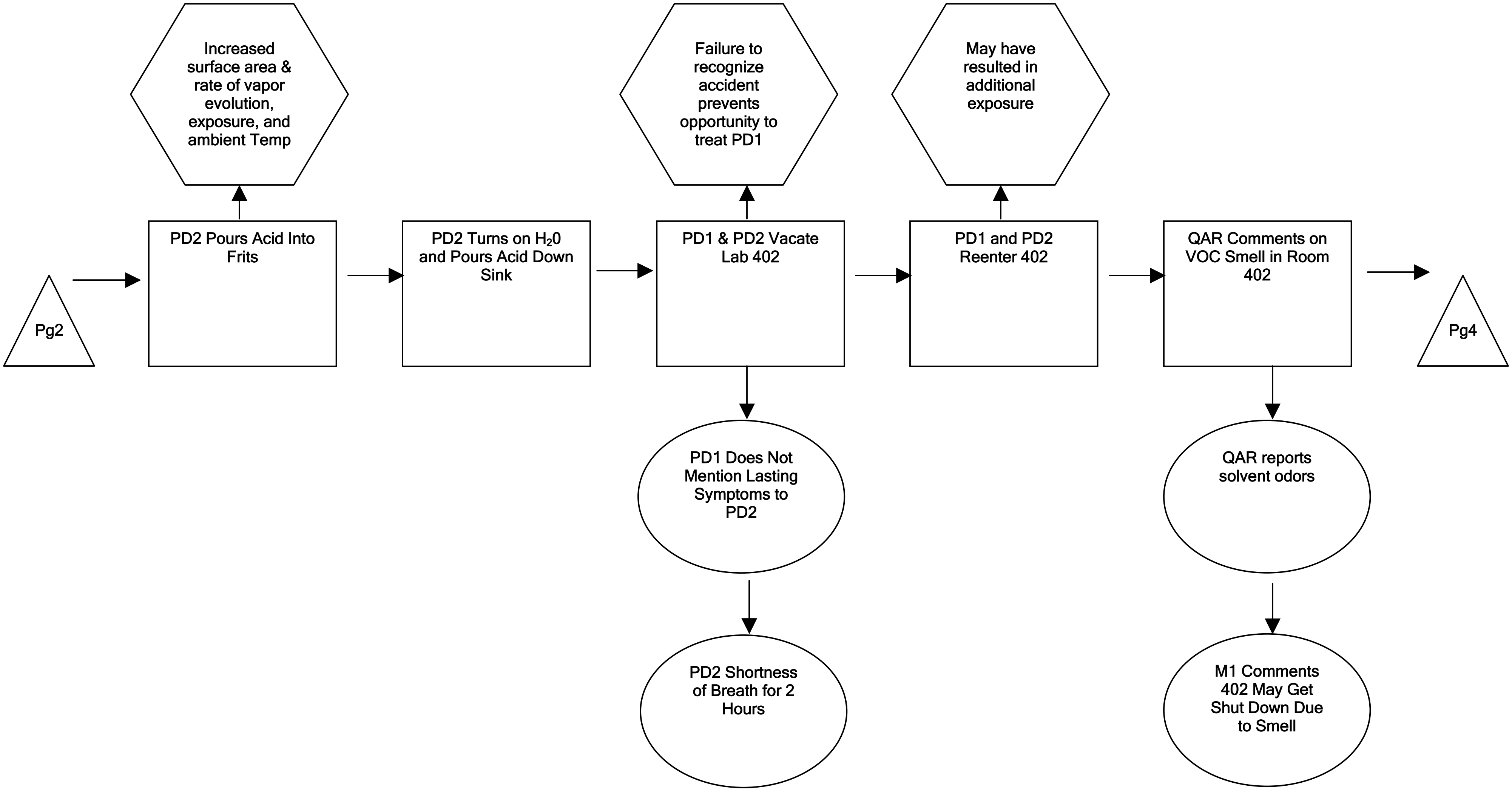
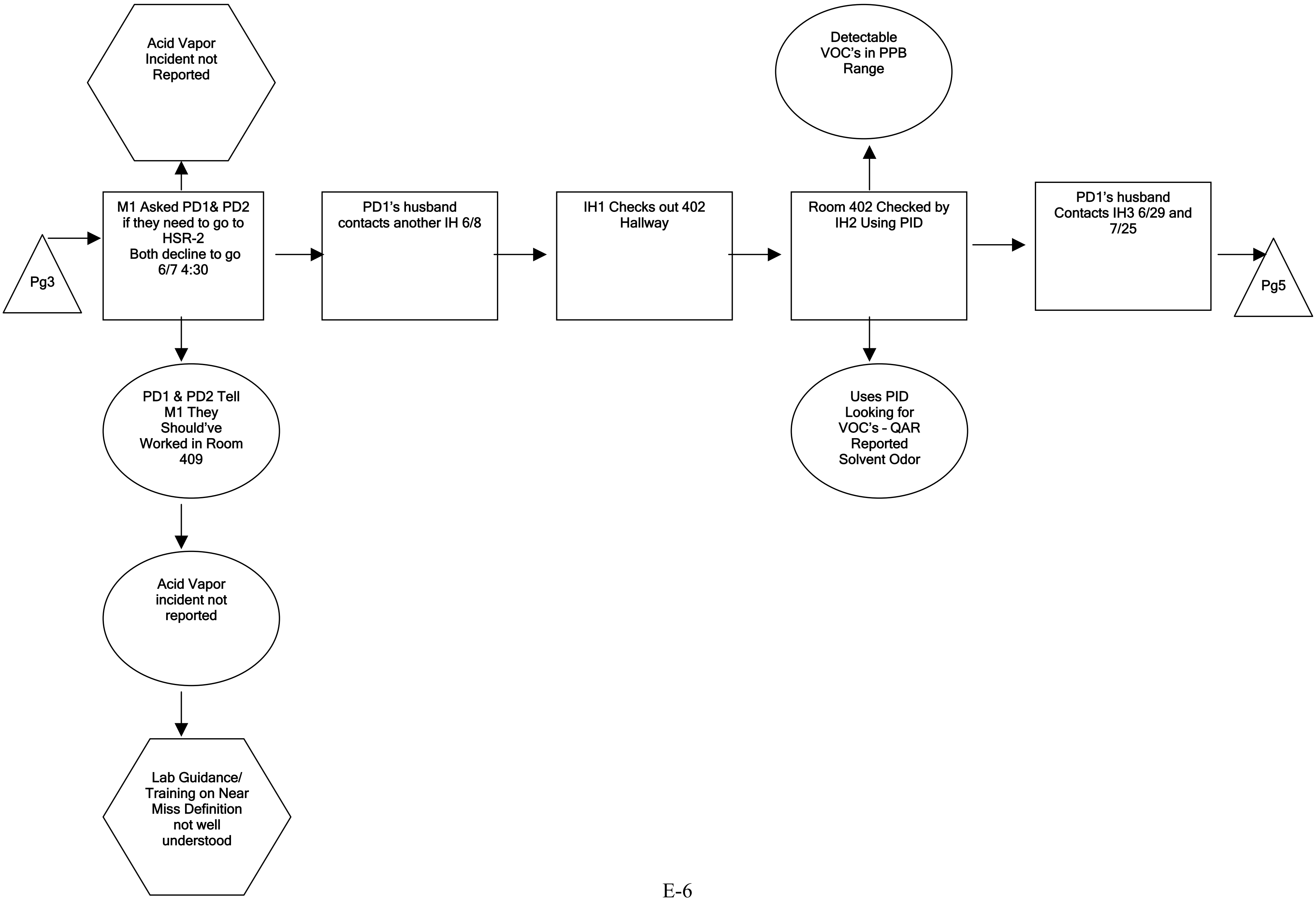
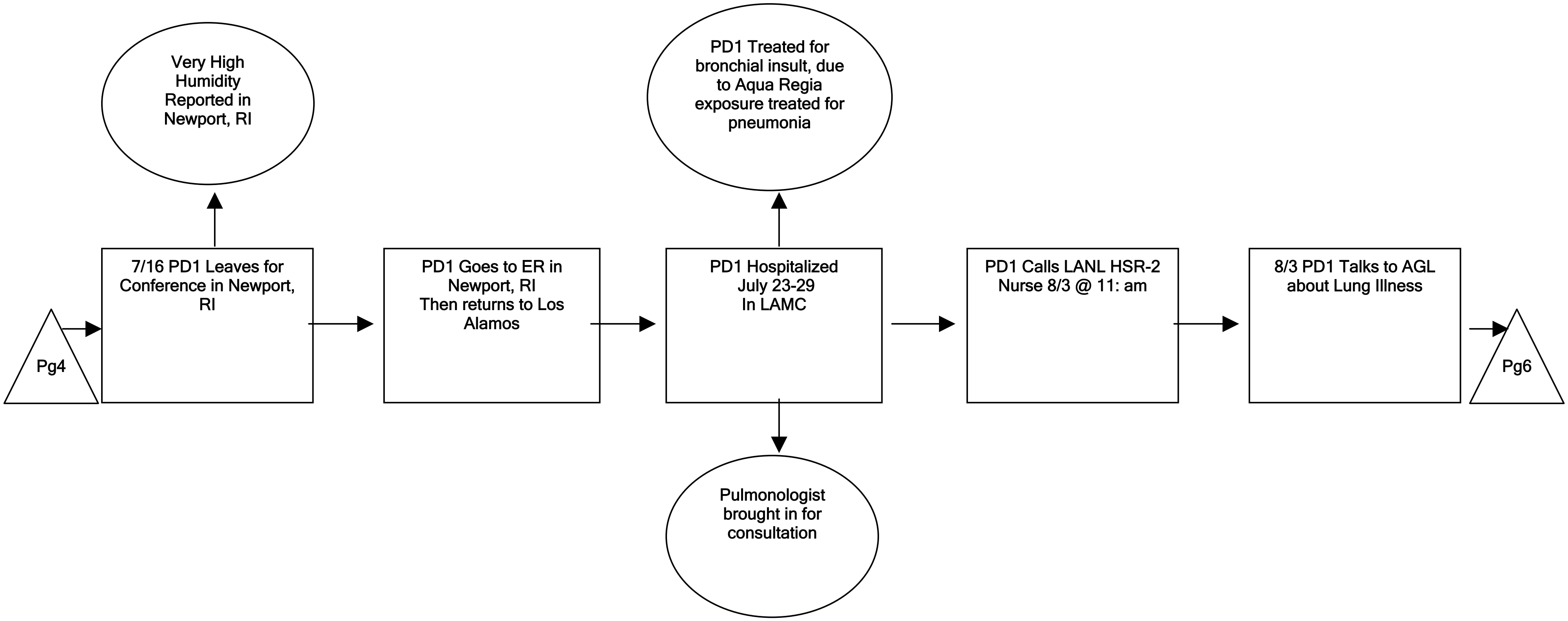
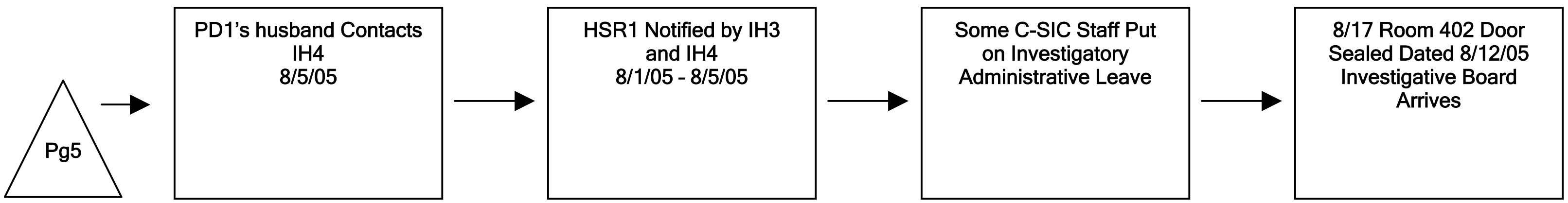

IWD Preparer Fails to Rate work as high hazard per IMP 300.2
PD1 & PD2s exhibit knowledge of Aqua Regia Haz. & Control
Aqua Regia hazards and controls not reiterated to PD1 & PD2
10/6/04 PD2 develops IWD Iding Frit cleaning with AR in Hood
M1 and PD1 sign IWD 10/8/04
Room 402 Hood Shut Down 5/16/05
5/18 C Div. Mgt. Emails 402 Open, Hood Not Working
6/7 11:am Meeting on 402 IWD Field Change Discussing Noxious Chem. Activities in Lab 409
Pg2
PD2 Exhibits knowledge of hazard and appropriate controls
M1 Not Trained as PIC
Aqua Regia Mentioned in Two Places in IWD 130-04
IWD Chem. Synthesis Doesn't ID Eng. Control For Acids
M1 Mentors PD1 March 2004
IWD Calls for Cleaning Glass Fritz in Hood Pg. 30 of IWD
M1 Mentors PD2 July 2004
PD2 Not Trained as IWD Prepared
- Event
- Condition
- Causal Factor
- Accident


Field Changes to IWD Don't ID Frit cleaning or control in Rm 409
Inadequate ventilation results in acid vapor exposure
Pg1
M1 makes Field Change to IWD C-SIC-130-04 6/7/05
M1 Met With QAR 2-4PM 6/7/05
PD1 Mixes Aqua Regia
PD1 Expresses Discomfort from Acid Vapor
PD1 & PD2 Exposed to Aqua Regia Vapors
Pg3
Training records indicates M1 not qualified as IWD Preparer or PIC
QAR Doing QA Audit
Fume Hood not functional HVAC down
Temp 90° -95° Increases Rate of Evaporation
6/7 IWD Field Change doesn't speak to Aqua Regia in Room 409
Temp in Room 402 90°-95° Doors Open
LASO FR TA-48 April -June 2005 but distracted by other duties
No WPF Specifically for Aqua Regia in Room 402
PD2 thought Nederman would Exhaust Fumes
Concentrating on location for UCL_4 Synthesis, as opposed to Aqua Regia


Increased surface area & rate of vapor evolution, exposure, and ambient Temp
Failure to recognize accident prevents opportunity to treat PD1
May have resulted in additional exposure
Pg2
PD2 Pours Acid Into Frits
PD2 Turns on H_20 and Pours Acid Down Sink
PD1 & PD2 Vacate Lab 402
PD1 and PD2 Reenter 402
QAR Comments on VOC Smell in Room 402
Pg4
PD1 Does Not Mention Lasting Symptoms to PD2
QAR reports solvent odors
PD2 Shortness of Breath for 2 Hours
M1 Comments 402 May Get Shut Down Due to Smell


Acid Vapor Incident not Reported
Detectable VOC's in PPB Range
Pg3
M1 Asked PD1& PD2 if they need to go to HSR-2 Both decline to go 6/7 4:30
PD1's husband contacts another IH 6/8
IH1 Checks out 402 Hallway
Room 402 Checked by IH2 Using PID
PD1's husband Contacts IH3 6/29 and 7/25
Pg5
PD1 & PD2 Tell M1 They Should've Worked in Room 409
Uses PID Looking for VOC's - QAR Reported Solvent Odor
Acid Vapor incident not reported
Lab Guidance/ Training on Near Miss Definition not well understood


Very High Humidity Reported in Newport, RI
PD1 Treated for bronchial insult, due to Aqua Regia exposure treated for pneumonia
Pg4
7/16 PD1 Leaves for Conference in Newport, RI
PD1 Goes to ER in Newport, RI Then returns to Los Alamos
PD1 Hospitalized July 23-29 In LAMC
PD1 Calls LANL HSR-2 Nurse 8/3 @ 11: am
8/3 PD1 Talks to AGL about Lung Illness
Pg6
Pulmonologist brought in for consultation



Pg5
PD1's husband Contacts IH4 8/5/05
HSR1 Notified by IH3 and IH4 8/1/05 - 8/5/05
Some C-SIC Staff Put on Investigatory Administrative Leave
8/17 Room 402 Door Sealed Dated 8/12/05 Investigative Board Arrives