Final Report **February 1998**

Type B Accident Investigation Board Report Chiller Line Rupture at Technical Area 35, Building 27 Los Alamos National Laboratory

Albuquerque Operations Office

This report is a product of an accident investigation board appointed by Bruce G. Twining, Manager, Albuquerque Operations Office, Department of Energy.

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

The discussion of facts, as determined by the Board, and the views expressed in this report do not assume and are not intended to establish the existence of any duty at law on the part of the U.S. Government, its employees or agents, contractors, their employees or agents, or subcontractors at any tier, or any other party.

This report neither determines nor implies liability.

On November 21, 1997, I established a Type B Accident Investigation Board to investigate the flooding incident at the Los Alamos National Laboratory, Technical Area 35, that resulted in property damage to Building 27.

The Board's responsibilities have been completed with respect to this investigation. The analysis process; identification of direct, contributing and root causes; and development of judgments of need during the investigation were done in accordance with DOE Order 225.1A, *Accident Investigations.*

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

Bruce G. Twining
Manager
Albuquerque Operations Office

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ACRONYMS

AHA	Activity Hazard Analysis
AL	Albuquerque Operations Office
BIO	Basis for Interim Operations
CAS	Condition Assessment Survey
DOE	U.S. Department of Energy
EM&R	Emergency Management & Response
FM	Facility Manager
FMC	Facility Manager Council
FMU	Facility Management Unit
FR	Facility Representative
FSS	Facilities, Safeguards & Security Division
HC	hazard category
JCNNM	Johnson Controls Northern New Mexico
LAAO	Los Alamos Area Office
LANL	Los Alamos National Laboratory
LIG	Laboratory Implementing Guides
LIR	Laboratory Implementation Requirements
LPR	Laboratory Program Requirements
LS	Laboratory Standards
M&O	Maintenance and Operations
MEL	Master Equipment List
NIS	Nonproliferation and International Security Division
ORPS	Occurrence Reporting and Processing System
PPE	personal protective equipment
PTLA	Protection Technology Los Alamos
SNM	special nuclear material
SSC	structures, systems and components
TA	Technical Area
UC	University of California

PROLOGUE

INTERPRETATION OF SIGNIFICANCE

The large property loss of $3.2 million at Los Alamos National Laboratory on November 17, 1997, was a result of failure by the University of California to protect the Department of Energy's assets. A chiller line ruptured because of freezing temperatures, and the water collected in the sub-basement of a building because of the failure of the sump system. As a result of the flooding there was a total loss of the contents in the sub-basement and damage to the building. Inadequacies in the Laboratory's maintenance program and lessons learned program contributed heavily to this incident.

Although the facilities and equipment were considered by line management to be old and deteriorating, adequate assessments were not made to determine the consequences to missions should equipment fail. Even though there were institutional maintenance standards, they were guidance and were not required to be implemented by line management. As a result, a freeze protection plan was not implemented. A complete approach to maintenance by the Laboratory is needed that emphasizes implementation of requirements and procedures, individual and line responsibility and accountability, effective training, and thorough oversight and feedback to management.

To prevent recurrence, line management must learn from previous incidents. Although information concerning other freeze protection incidents were known by the Laboratory, they did not ensure that the applicable lessons learned were implemented institutionally.

INTRODUCTION

A property damage incident which occurred at the Los Alamos National Laboratory (LANL), Technical Area 35 (TA-35), Building 27, was investigated since the estimated damage was expected to exceed one million dollars. During the investigation, the DOE Accident Investigation Board (Board) used various analytical accident investigation techniques including accident analysis, barrier analysis, and event and causal factor analysis. The Board observed the function tests of the mechanical equipment involved in the incident, inspected the incident site, reviewed events surrounding the incident, and conducted extensive interviews and document reviews to determine the factors that contributed to the incident. Relevant management systems were also evaluated in accordance with DOE Order 225.1A, *Accident Investigations.*

INCIDENT DESCRIPTION

The incident was discovered at approximately 6:45 a.m., on Monday, November 17, 1997, when a Protection Technology Los Alamos (PTLA) employee responded to a security alarm. Sometime past normal working hours (after 5:00 p.m.) on Friday, November 14, 1997, a chilled water system froze, rupturing its copper coil at several locations. The incident resulted in flooding of the sub-basement of TA-35 Building 27 with 58½ inches of water. This caused $3.2 million in damage to the facility and to the equipment used for Nonproliferation and International Security operations.

LANL has ensured the safety and health of the workers during the clean-up activities. Plan of the day meetings were held each day to cover the activities along with the potential hazards. Controls were established and verified to reduce injury and illnesses. Clean-up is ongoing because of health concerns from the water damage.

CAUSAL FACTORS

The direct cause of the incident was the improper setting of the reservoir setpoint temperature, which caused the dampers to remain open during subfreezing temperatures.

The root causes were: (1) failure by LANL to implement an effective institutional lessons learned program, (2) failure by LANL to ensure the facility management organization was knowledgeable of the operations of the mechanical systems, (3) failure by LANL to ensure the roles and responsibilities of the facility management organizations were clear and understood, (4) failure by LANL to establish maintenance requirements, and (5) failure by LANL, to provide oversight of facility management maintenance activities.

The contributing causes were: (1) maintenance categorization of equipment was incorrect, (2) maintenance was not conducted more frequently based on established criteria, (3) legacy design features were not reevaluated after the facilities and mission changed, (4) failure by DOE/AL and LAAO to provide oversight of the FM maintenance activities, and (5) radiological source control was not completely developed and implemented.

CONCLUSIONS AND JUDGMENTS OF NEED

Table ES-1 presents the conclusions and judgments of need determined by the Board. Conclusions of the Board are those considered significant and are based upon facts and pertinent analytical results. Judgments of need are managerial controls and maintenance practices believed by the Board to be necessary to prevent or mitigate the probability or severity of a recurrence of this type of incident.

Conclusions	***Judgments of Need***
Application of lessons learned from freeze protection incidents was not effective.	LANL needs to ensure that institutional corrective actions are uniformly and promptly implemented. LAAO needs to establish a process to ensure important institutional corrective actions, based on lessons learned, are implemented at LANL.
FMU-75 did not develop a freeze protection plan and LANL did not ensure that a freeze protection plan was developed.	LANL needs to establish requirements for FMUs to develop a freeze protection plans and ensure they are implemented at all FMUs.
FMU-75 did not take actions to protect TA-35, Building 27 sub-basement from a flood.	LANL needs to re-evaluate equipment categorization and "legacy design" for failure modes to prevent potential flooding. LANL needs to ensure operability of all safety equipment including sump pumps in the basement and sub-basement.
NIS-5 did not complete planned radiological source control actions which would have facilitated flood response and minimized flood damage.	NIS-5 needs to complete radiological source control and storage actions.
Institutional maintenance management program lacks clear requirements, training, and oversight.	LANL needs to evaluate current requirements or establish requirements for the categorization, maintenance, and surveillance of systems. Clear roles and responsibilities and associated training to provide understanding of both responsibilities and operations need to be developed. Evaluation of performance through oversight to these requirements needs to be performed to provide institutional consistency and incorporation of shared corporate knowledge between FMUs. All FMs need to be held accountable for the operation of the facility.

The reduction in staff and qualified individuals resulted in inadequate oversight of the institutional management maintenance program.	DOE/AL and LAAO need to strategically align resources in order to provide oversight of the maintenance management program

1.0 INTRODUCTION

1.1 BACKGROUND

On November 17, 1997, at approximately 6:45 a.m., a Protection Technology Los Alamos (PTLA) Security Guard investigated a security alarm at Los Alamos National Laboratory (LANL),Technical Area 35 (TA-35), Building 27. The alarm was initiated because of the hydrostatic pressure on the door or water damage to the electronics of the security alarm. Upon entry into the building, the guard discovered that the sub-basement level of the facility was flooded. An estimate of the property damage associated with the flooding condition was initially determined to be $300,000. After additional evaluation by the user group, this estimate increased to approximately $1,000,000 in damage. On November 21, 1997, Bruce Twining, Manager, Albuquerque Operations Office (AL), US Department of Energy (DOE) established a Type B Accident Investigation Board (Board) to investigate this incident in accordance with DOE Order 225.1A, *Accident Investigations.* The appointment letter can be found in Appendix A.

On November 17, 1997, a PTLA Security Guard investigated an alarm at TA-35, Building 27 and discovered the 3rd floor sub-basement flooded.

On November 21, 1997 a Type B Accident Investigation Board was established by the Albuquerque Operations Office.

1.2 FACILITY DESCRIPTION

LANL, located in north-central New Mexico, is operated by the University of California (UC) under contract to DOE. Its primary mission is to enhance national security by applying its scientific and engineering capabilities to nuclear weapons technology. LANL also performs other work not related to nuclear weapons technology. LANL occupies 43 square miles and consists of 47 active technical areas managed by twenty Facility Management Units (FMU).

The scene of this incident, TA-35, Building 27, is the responsibility of FMU-75, which reports to the Nonproliferation and International Security (NIS) Division. Building 27 has three floor levels where work is conducted. The main tenant is the Safeguards, Science and Technology Group, NIS-5. The first floor (ground level) consists mainly of office and administrative work areas. The NIS-5 group office resides there, as well as the training and publications section. There is one small radiological source storage repository on this floor. There is also an equipment staging area termed the “high bay.”

The second floor (basement) is also primarily office space. There is one room used for archival storage and another used for storage of surplus electronic equipment. The main experimental area is the “hot cell” or shield cell. The hot cell is also used for radiological source storage.

The third floor (sub-basement), where the flooding occurred, is used primarily for four programmatic efforts. The programs currently in progress are (1) the Inertial Electrostatically Confined Plasma Neutron Generator, (2) training classes usually in gamma-ray techniques, (3) calibration activities supporting material control and accountability programs, and (4) Remote Monitoring Project. In addition, the sub-basement is used for sealed radiological source and small amounts of special nuclear material (SNM) storage. The SNM is stored inside the vault, which is a locked room inside the pipe room. The pipe room is also locked and secure. The pipe room itself is used also for training in “hold up” measurements. Radiological sources are stored in the “cage”, which is adjacent to the sub-basement hot cell. The sub-basement hot cell is similar in design and operation to the basement hot cell.

A Basis for Interim Operations (BIO) for Building 27, which documents approval to conduct operations, was signed by the Facility Manager, NIS-5 Group Leader and NIS Division Leader on June 19, 1996. The BIO indicates that Building 27 was classified as a Hazard Category 3 (HC-3) nuclear facility based on a direct comparison with the radionuclide threshold limits per DOE-STD-1027, “Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports.” The BIO also indicates a determination that Building 27 had negligible onsite and off-site consequences for the worst unmitigated accident. There was no accident scenarios described in the BIO that addressed flooding in the basement.

1.3 CHILLED WATER AND SUMP SYSTEM OPERATION

The chilled water system provides chilled water for the facility.

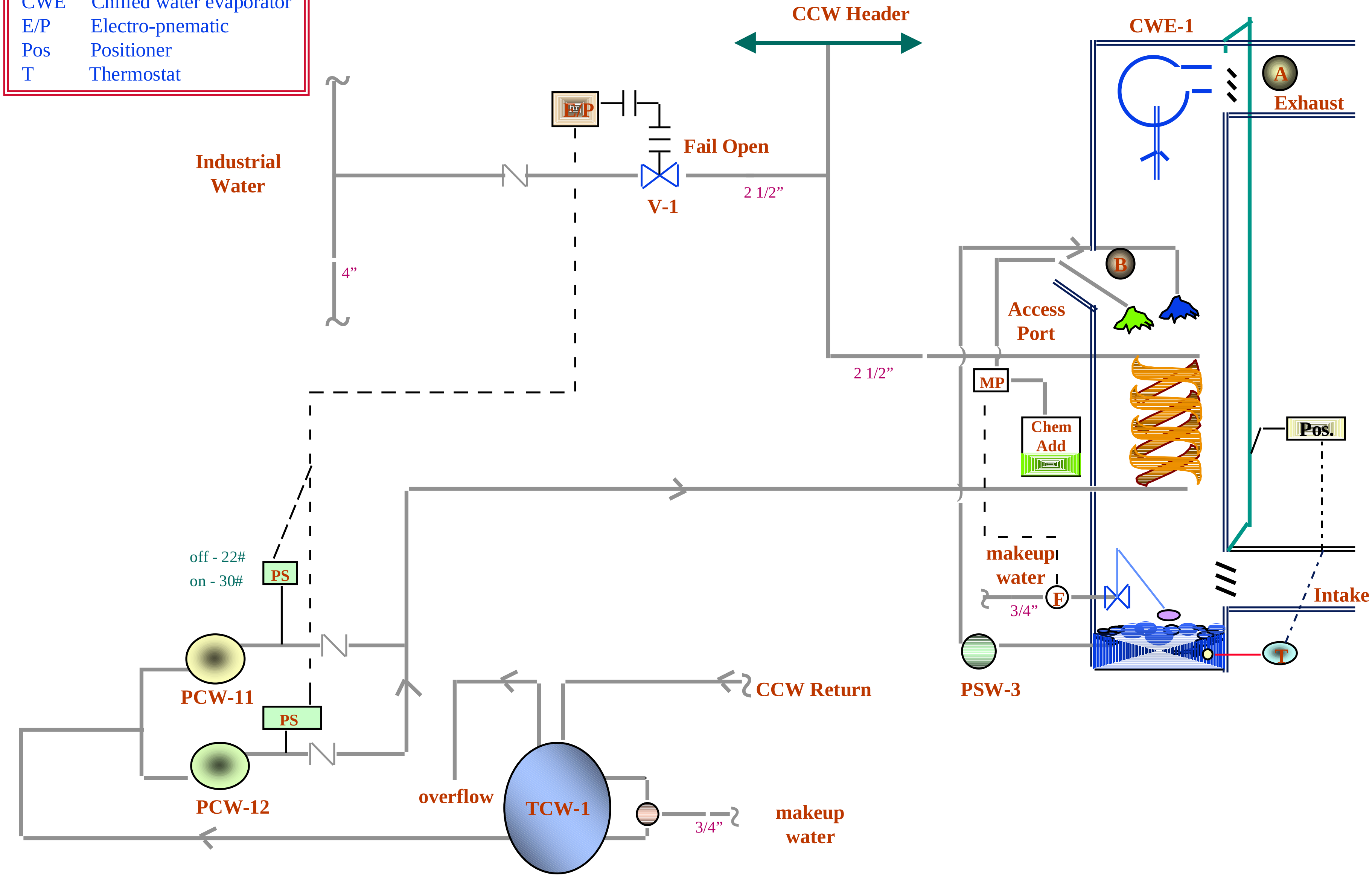
The chilled water system for TA-35, Building 27 provides chilled water for ventilation cooling for the first-floor computer room and other cooling loads within the facility. None of these loads is considered mission-critical. A schematic diagram of the chilled water system is found in Figure 1, and Figure 2 shows a photograph of the chilled water system. The chilled water system is a closed-loop system that consists of two full-capacity chilled water pumps (PCW-11 and PCW-12), which take a suction on a storage tank (TCW-1), and pump the water through a chilled water evaporator (CWE-1) and out to the chilled water header. The return flow enters tank TCW-1 through a return header. The tank has an automatic makeup system to maintain a prescribed level. The pumps operate one at a time and can be manually shifted from a single control switch. The chilled water is cooled in the CWE-1 which is located on the first floor. CWE-1 consists of a fan which draws outside air over the cooling coils. A set of mechanically interlocked dampers are modulated through a single temperature control sensor to maintain the chilled water at a temperature within a 3-degree preset operating band. The temperature is sensed from a reservoir of water that is below the cooling coils. A separate system sprays water from the reservoir across the cooling coils.

The chilled water system contains a legacy, automatic emergency "feed and bleed" mode of operation.

The system also contains an automatic emergency "feed and bleed" mode of operation. This feature was a legacy design from the late 1960's in order to provide emergency cooling to a flux reactor that was never installed. An electro-pnuematic relay, which is energized through a pressure switch located on the discharge side of the chilled water pumps, provides air pressure to keep shut a pneumatically-operated valve (V-1). In a normal operating condition, this isolates the chilled water system from the industrial water system. If the running chilled water pump loses outlet pressure, the pressure switch opens and vents the air off the valve, allowing industrial water at a pressure of 100 psi to flow into the chilled water system through the header to tank TCW-1. The water fills the tank and then exits through an overflow line that dumps on the pavement outside of the building. In this mode of operation the cooling coils have no flow due to check valves located at the discharge of the

Figure-1 Chilled Water Evaporator

PCW	Pump chilled water
PS	Pressure switch
TCW	Tank for chilled water
CCW	Cold chilled water
PSW	Pump spray water
CWE	Chilled water evaporator
E/P	Electro-pnematic
Pos	Positioner
T	Thermostat



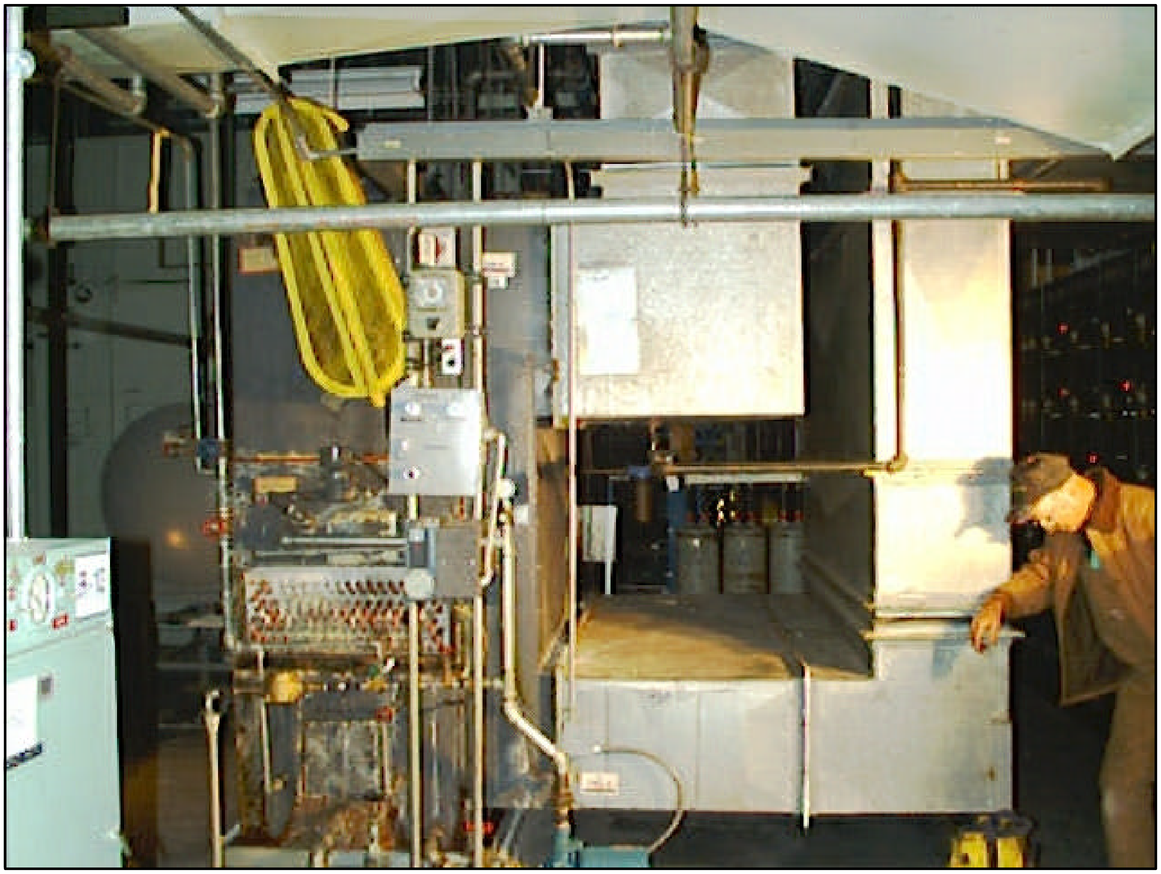


Figure 2: Chilled Water Evaporator (CWE) - 1

Figure 3: Sump Pumps (PS-1 & PS-2)

pumps. When the pump discharge pressure is restored above the pressure switch reset point, valve V-1 shuts.

A sump system located on the sub-basement has two 80-gallon/minute sump pumps, which alternate in a first stage configuration and then simultaneously if water reaches a second stage point as determined by a float in the sump pit. A shroud protects the float-activated switches (Figure 3).

1.4 SCOPE, PURPOSE, AND METHODOLOGY

The Board began its investigation on November 24, 1997, and completed its investigation on December 19, 1997. On January 6, 1998, the Board submitted its findings to the AL Manager.

The scope of the Board's accident investigation included all activities required to review and analyze the circumstances surrounding the accident and to determine the causes. During the investigation, the Board inspected the accident scene and associated property damage, reviewed information and photographs provided by the Facility Manager (FM), observed the testing of the mechanical systems after power was restored, reviewed the events leading to the incident, reviewed the emergency response and incident clean-up, conducted extensive interviews and document reviews, and performed various accident investigation techniques. The Board also evaluated the adequacy of the contractor's maintenance system.

The scope of the Accident Investigation included all activities required to identify the cause of the accident.

The purpose of this investigation was to identify causal factors of this incident, including deficiencies, if any, in the operation and maintenance of the affected systems. The investigation report will inform the DOE community of lessons learned to promote improvement and to reduce the potential for similar incidents resulting in property loss.

The purpose of the investigation was to identify causal factors in order to inform the DOE community of lessons learned.

The Board conducted its investigation, with focus on management systems, using the following methodology:

- The Board gathered facts relevant to the incident;
- The Board interviewed personnel associated with the incident;
- The Board evaluated relevant management systems and factors, and

- The Board analyzed barrier and event and causal factors to determine the causes of the incident and the causes of the extensive property damage.

2.0 FACTS AND ANALYSIS

2.1 ACCIDENT DESCRIPTION AND CHRONOLOGY, EMERGENCY RESPONSE, INVESTIGATIVE READINESS, AND SITE CLEAN UP

The flooding of TA-35, Building 27 was due to the rupture of the CWE-1 copper cooling coils caused by freezing. The coils ruptured in a number of locations (See Figure 4). These were primarily at bends in the coils; however, a number of ruptures were found in the center portion of the coils. The freezing and subsequent numerous ruptures took place after 8:00 p.m. on Friday, November 15, 1997. Following the ruptures of the cooling coils, water flowed (estimated at 200 - 250 gallons/minute) into the mechanical room and primarily down the east stairwell flooding the sub-basement of the facility.

Inspection of CWE-1 the day after the incident was discovered revealed that one vane of the outlet damper (see location A on Figure 1) was stuck in the open position because of a broken linkage arm. It was also noted that the temperature sensor for this system was set at 32 degrees Fahrenheit rather than the 55-degree setting indicated on the operator aid posted nearby (See Figures 5 and 6). In addition, an access port was opened above the coil stack with the cover plate of the port lying on the ground next to the unit. The Board determined that only the temperature sensor setting contributed to the incident.

The flooding in Building 27 was discovered because of a security alarm.

At approximately 6:45 a.m., November 17, 1997, PTLA responded to a security alarm in TA-35 Building 27. The security officer discovered the flooded condition of Building 27 and reported the condition to the Facility Support, Johnson Controls Northern New Mexico (JCNNM) Utilities. They in turn contacted Facility Management at TA-35 and Emergency Management and Response (EM&R), who contacted Nuclear Materials Control & Accountability Group, FSS-12; Nuclear Criticality Safety Group, ESH-6; Water Quality & Hydrology Group, ESH-18; and the Los Alamos Area Office (LAAO). Facility

Support personnel shut the water supply to the CWE-1. At approximately 7:30 a.m., the FM arrived at the building. No formal incident command was established by EM&R, since they considered facility management to have the situation in control. EM&R did remain at the scene to provide any needed technical support.

At 7:50 a.m., electrical power to the building was turned off at the sub-station. ESH-6 began reviewing the inventory of sealed radiological sources and evaluating potential criticality issues. The criticality evaluation that was conducted revealed no concern because the plutonium was stored in 6M drums and the uranium was mostly of moderate enrichment. At 8:20 a.m., a critique was held with specialists in electrical, mechanical, radiation, hydrology, waste treatment and waste management to identify issues and develop plans to mitigate the incident. At that time, it was determined that the sub-basement held about 400,000 gallons of water based on a water level of 58½ inches. Between 10:00 a.m. and 12:00 noon, samples were taken of the water in the stairwell for radioactivity analysis. Tests of the samples indicated that there was No Detectable Activity (NDA) for gamma, alpha and beta radiation; however, tests for tritium indicated a level of 38 picocuries per liter. This level was within background levels for tritium (50 pCi/L). The waste treatment specialist determined the water could be pumped to the waste treatment plant. Tests were also conducted to determine if there was any oil or other chemicals in the water so that the water could be pumped into the sewer. Tests for these constituents indicated that there were no detectable levels. At the same time, dumpsters were dedicated and stationed to collect and hold the trash for release.

It was determined that the sub-basement held about 400,000 gallons of water based on a water level of 58½ inches.

Tests were conducted to determine if there was any oil or other chemicals in the water so that the water could be pumped into the sewer.

At 1:30 p.m., a review of the electrical concerns was held by the FM, Division Electrical Safety Officer, Support Services Electrical Safety Officer, and the Area Coordinator. It was determined that a generator could be connected to the distribution panels at the ground level to provide electricity to the pumps. At 6:20 p.m., pumps brought in from off-site began pumping out the water. All pumps were fitted with screens to ensure that no radiological sources were inadvertently discharged to the waste treatment facility. Pumping continued until 1:40 p.m., November 18, 1997, when the water level dropped to a level of eighteen inches. A survey team composed of the

An electrical safety assessment of the sub-basement was conducted.

Figure 4: Ruptured Coils of CWE-1

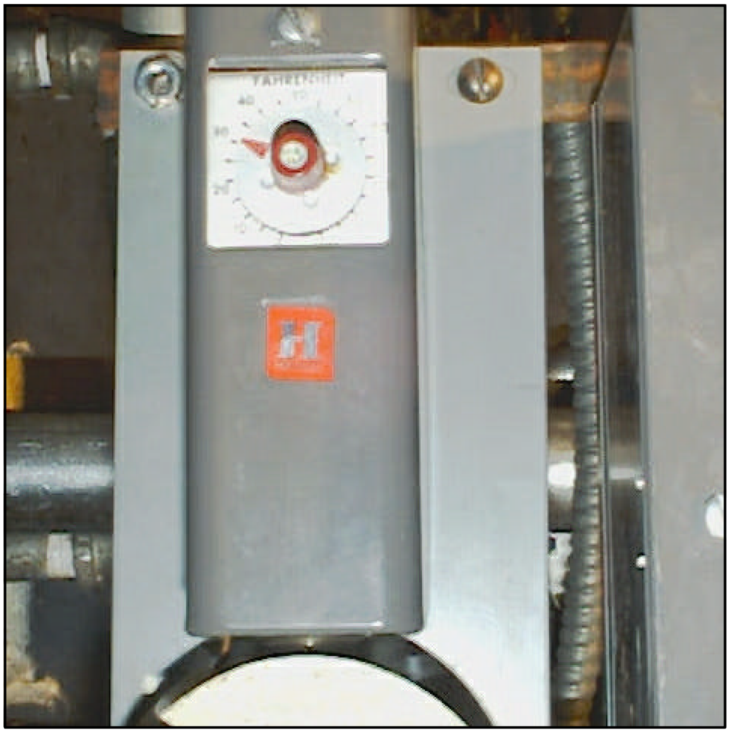


Figure 5: Thermostat Set at 32 Degrees Fahrenheit

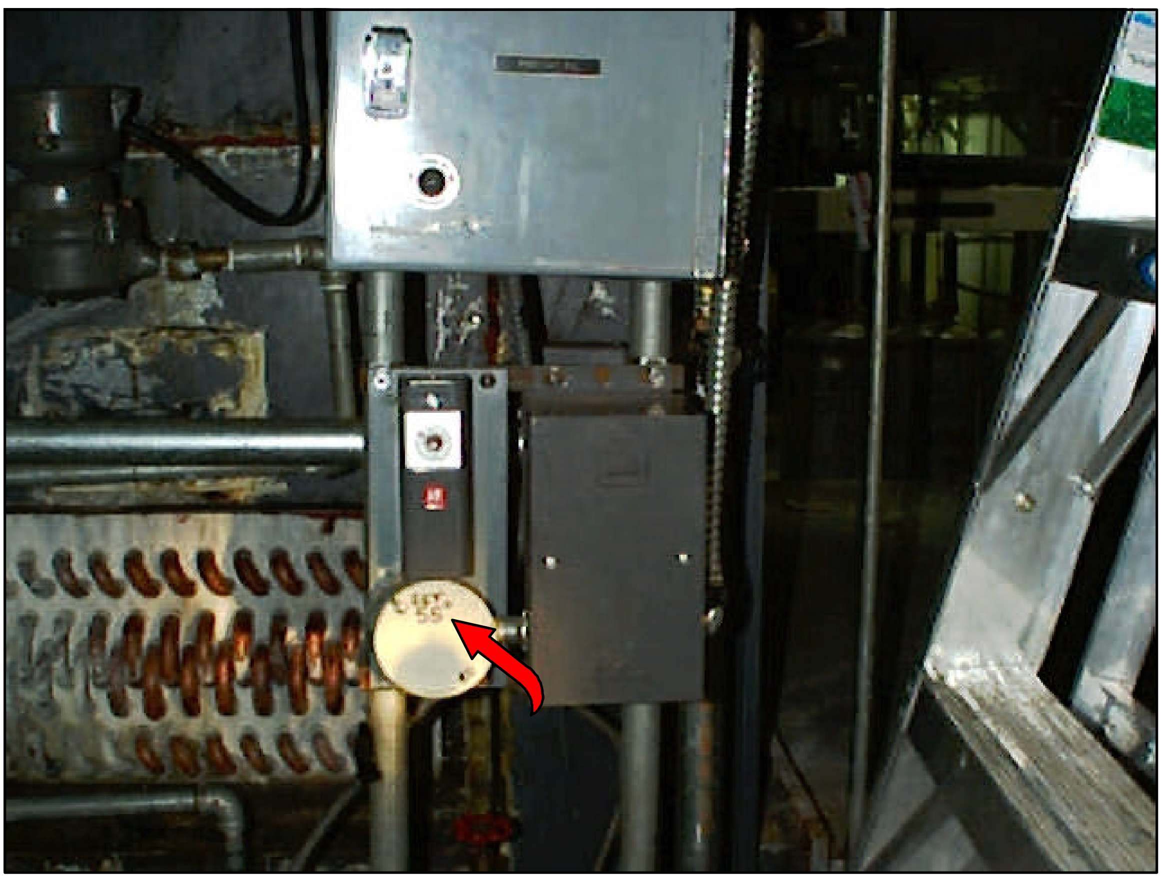


Figure 6: Thermostat with note set at 55 degrees Fahrenheit

electrical safety officers entered the sub-basement to assess the damage. All power sources were locked and tagged out before entry. The team also wore boots and gloves rated for 1 kVa while working in this area in case there was an unknown electrical supply source which fed the building. During this assessment, the team disconnected the electrical equipment from the outlets. When surveying the closed pipe room in the sub-basement, the team noted possible evidence of oil. Additional tests were taken for oil, grease and poly-chlorinated biphenyls, and pumping remained suspended until the results of these tests were determined.

Test results were negative, so pumping resumed at 3:40 p.m., November 19, 1997. Pumping continued until the water level reached a level of one inch. On November 20, 1997, personnel entered the flooded area to assess the damage. Again, the team members wore appropriate personal protective equipment (PPE).

On November 21, 1997, the custodians entered the sub-basement area, wearing PPE, to remove the remaining water. Before personnel entered the sub-basement area, power sources were locked and tagged out. In addition, the custodial staff did not use any powered equipment when removing the remaining water. On November 22, 1997, the electricians began analyzing, cleaning, and replacing electrical distribution equipment in the flooded area. On November 26, 1997, the electrical power was restored to the building. The FM initiated clean-up and property inventory measures, which are ongoing, because of general industrial safety and health concerns.

Plan-of-the-day meetings were in place to ensure proper controls were in place during clean-up activities.

Daily plan-of-the-day meetings were held among TA-35 facility management and the clean-up workers. During these meetings, activities for the day were discussed, along with the hazards and control of these hazards. The main focus of these meetings was worker safety and health with the goals of pumping all the water out of the building, returning the building to safe electrical operation, and verifying the location of all nuclear material. In addition to the meetings, the site's work control process covered the clean-up activities. Activity Hazard Analyses (AHAs) were developed for each of the crafts involved in the clean-up. Review of these documents show that these AHAs were generic and did not specify the controls and PPE used during the clean-up. However, plan-of-the-day meetings ensured that proper controls were in place during the clean-up activities.

There were over 200 sealed radiological sources and SNM located in the sub-basement of the facility. Once the level of the water dropped to the one-inch level, the goal was to locate these sources. To ensure an accurate and complete accountability of the radiological sources, NIS-5 conducted a full inventory of all radiological sources assigned to them. The radiological source removal log for the sub-basement “cage” indicated only one radiological source was logged out at the time of the flood. It was determined that the one logged out radiological source was a Cesium-137 source that was being used in the pipe room. This radiological source was not stored in the secure cage location and it was recognized that it would have to be searched for. It was found near an unscreened drain. In fact, all drains were unscreened; however, screens were placed on the drains after the survey was conducted at the one-inch water level.

There were over 200 sealed radiological sources and SNM located on the sub-basement of the facility.

NIS-5 conducted an SNM inventory in the pipe room and the vault. All SNM was accounted for immediately. All plutonium had been stored in 6M, Type B drums and was both secure and dry. NIS-5 conducted a radiological source inventory in the cage. As a result of the flooding several radiological sources had fallen off the shelves. The radiological source inventory of non-SNM was incomplete, and a total of seven radiological sources were missing. Two additional inventory checks were performed between November 24, 1997, and December 1, 1997, before 100% radiological source accountability could be ensured.

A total of three inventory checks were performed between November 24, 1997 and December 1, 1997 before 100% accountability could be ensured.

On November 24, 1997, contamination was detected on three personnel booties, the highest level being 1200 counts per minute (cpm); based on analysis it was believed to be Cesium-137. On November 25, 1997, large area swipes were performed in the cage and hot cell and indicated low levels of removable contamination. After the inventory of the radiological sources was completed, a leak survey was scheduled by NIS to determine the extent of damage to the radiological sources.

Actions taken by LANL to preserve the integrity of the incident scene were effective. PTLA secured access to the site and the FM controlled access to the building. Numerous digital photographs were taken of the incident and property

Actions taken by LANL to preserve the integrity of the incident scene were effective.

damage. The evaluation of the electrical equipment loss was not performed until after the Board convened at the site. The LAAO backup Facility Representative (FR) responded to the scene and returned the following day to attend the critique. It was determined after the critique that this incident should be classified as a Type B Accident since at this point, the amount of damage could exceed one million dollars. The LAAO accident investigation point of contact requested that the contractor continue in its clean-up activities and maintain control of workers entering the facility. There was delay in forming the Board. Because of this delay, the Board did not convene at the site until November 24, 1997. At that time, a briefing was given by the FM detailing the clean-up activity. The minor deficiency involving the timely selection and mobilization of the Board did not affect the outcome of this investigation.

2.3 EXTENT OF WATER DAMAGE

The flooding of the sub-basement of Building 27 caused minor damage to the facility and radiological material and extensive damage to experimental equipment. Figures 7 through 11 illustrate examples of the damage. In the sub-basement, major portions of the electrical distribution system (breakers, transformers, receptacles) had to be replaced due to water damage. Radiological sources were damaged because of the flooding and subsequent submersion. Six of the sources were found to be leaking, and twenty had cross contamination. The cross-contamination was a result of the sealed source recovery and staging for subsequent disposition. Two radiological sources had contamination levels of less than 2200 dpm/100 cm^2 for either alpha or beta-gamma. The NIS-5 group leader indicated that all leaking radiological sources would be disposed of unless they could be refurbished.

The flooding of the sub-basement of Building 27 caused extensive damage to the facility, experimental equipment and radiological material.

A damage report compiled by FMU-75 indicated a total cost estimate of $3.2 million for the flooding of Building 27. This report was provided to the Board on December 18, 1997. The $3.2 million represents $125,000 for facility costs which includes clean-up, emergency response, fire protection, roads and grounds, and other miscellaneous costs. About $1.3 million dollars is attributed to the acquisition cost of bar-coded equipment and $1.8 million is attributed to the acquisition cost of scientific equipment

A damage report compiled by FMU-75 indicated a total cost estimate of $3.2 million for the flooding of Building 27.

Figure 7: Debris floating in water in sub-basement

Figure 8: An office in sub-basement, note water mark on wall

Figure 9: Debris floating in sub-basement with one inch of water

Figure 10: Damaged transformer in sub-basement

Figure 11: Radiological source storage

(i.e., joint research equipment with Russia). The $3.2 million cost estimate assumes that the majority of all equipment located in the sub-basement was damaged beyond repair.

2.4 MANAGEMENT SYSTEMS

2.4.1 Policy and Procedures

LANL has a hierarchy of requirements comprising Laboratory Program Requirements (LPR), Laboratory Implementation Requirements (LIR) or Laboratory Standards (LS), Laboratory Implementing Guides (LIG), and in the case of maintenance activities, Maintenance and Operations (M&O) Standards. The LPR are performance requirements that individual Division Directors are expected to follow. The following standard statements are examples taken from the maintenance LPR:

- Maintenance history is documented and used to support maintenance activities.
- Preventative maintenance is conducted in an effective manner and contributes to effective performance and reliability of systems, structures and components.
- Maintenance is conducted in an effective and efficient manner.
- The condition of facility systems, structures and components support safe and reliable operation.
- Each facility is managed throughout its life cycle so that its capability meets program needs.

The LIR establishes operational requirements for Divisions in order to provide consistency in key institutional processes at LANL. For maintenance, LS 121-01.1, *Categorization of Systems & Equipment Via the Graded Approach*, and LS 121-02.0, *Graded Approach to the Conduct of Maintenance,* are in effect until a LIR is specifically written to address maintenance management.

LANL Standard 121-01.1 requires that when assigning systems to a graded approach category of consequence, the worst-case credible failure mode should be assumed. In determining the worst-case failure mode and credibility, the following considerations are presented: failures of similar systems, operating history, weak points in the system, and insufficient maintenance. The categorization of each identified system should be recorded in the facility Master Equipment List (MEL). Attached to the standard is an example listing of generic systems and equipment with a recommended graded approach category. Chilled water systems or sump pumps are not specifically listed; however, waste systems are designated as M3. CWE-1 was classified by FMU-75 as a category M4 along with sump pumps PS-1 and PS-2. To be classified as category M4, the failure of the structure, system, or component would have no impact on the public or workers, but may cause minor damage to the facility. Category 4 equipment requires only good business/maintenance practice in order to remain operative.

LS 121-02.0 requires implementation of a maintenance program based on guidance provided in the document. Facility managers are also required to grade their systems, develop equipment lists, and assign appropriate maintenance resources. An attached matrix in the standard identifies required documentation based on the grade. This documentation includes: cost identification, modifications and additions, maintenance procedures, post maintenance testing, surveillance, preventative maintenance, predictive maintenance, and seasonal service and freeze protection. However, M4 equipment requires only cost identification for real property. Freeze protection for M4 equipment is listed as "should be considered" rather than "shall" in this standard.

For maintenance, LIG 207-00-01.0, *Maintenance Procedures and Training*, provides guidance for development of maintenance procedures. The guide focuses on the procedures for recurring scheduled maintenance that may be considered preventive or predictive. The guidance outlines the need for formal procedures based on equipment categorization. If the equipment is classified as M4, then formal procedures are not required and "Skill of the Craft" is the recommended practice. The equipment involved in this incident is classified as M4. Although procedures are not required, the document provides guidance in determining the maintenance activities to be performed along with the frequency. Consideration for type and frequency of maintenance should include seasonal changes (freezing) and when records indicate a significant change in reliability.

The LANL Maintenance and Operations Standards Manual is a collection of the Maintenance & Operations Standards that are not specific to any single piece of equipment. The M&O Standards statement of authority signed by the Facility Manager Council (FMC) Chairperson and the Facilities, Safeguards & Security (FSS) Division Director states, "This manual sets minimum maintenance and operations (M&O) standards adopted by the Facility Manager Council … and the Facilities, Security and Safeguards (FSS) organizations responsible for M&O management. In adopting these standards, the FMC and FSS Division recommends their implementation, but individual Facility Managers are responsible for planning the implementation of these standards at their Facility Management Unit (FMU)."

The FMC and FSS Division recommends implementation of maintenance standards .

LANL Maintenance and Operations Standard MO 3.7-600, Rev. 0, issued on October 22, 1997, addresses freeze protection. This standard was developed as a corrective action to an occurrence report (ALO-LA-LANL-1996-0007). The standard requires a freeze protection plan, itemizing property and equipment to be protected, and planned actions with scheduled and completion dates. There are no examples provided in the standard to assist in the development of a plan. This standard requires tests of systems controlled by dampers; however, this test was not conducted on CWE-1. The FMU has only an informal freeze protection checklist at TA-35, Building 27, but no freeze protection plan was developed. However, there was no inclusion of the testing of dampers and associated controllers in the checklist. During the interview process, the FM stated that he was disappointed to find that there was no official plan for freeze protection.

At TA-35, Building 27, no freeze protection plan was developed.

2.4.2 Roles and Responsibilities

FMU-75's mission is to support the programmatic goals of the personnel residing in the facility by managing the physical plant and providing Building Manager service for each building. In order to accomplish this mission, FMU-75 has created an organizational team comprising the FM, three Facility Coordinators, Area Coordinator, Safety Engineer, and a Radiological Control Technician. The major tasks of the team include: liaison with FSS personnel for maintenance support; schedule, track, and report all facility maintenance activities; manage the funds for facility

FMU-75 supports programmatic goals of residing personnel by managing the plant.

maintenance; coordinate repairs and resolution of deficiencies that require action by support groups; oversee crafts performing maintenance; maintain work order control system; plan for upgrades; serve as the point of contact for all facility modifications; initiate work orders; assure that facility-owned equipment is inspected as required and records are maintained; identify critical systems; and develop and implement the maintenance management program for the facility. In addition, the facility management is to conduct management walkthroughs to ensure facility work is conducted safely. The responsibilities of the FM with respect to the facility infrastructure were clearly understood by tenant organizations.

Per LIR 280-02-01.0, *Laboratory Facility Management Program*, the Division Director has the ultimate authority for the assigned facilities. The FM is a line manager and an agent of the owning Division Director, and has the authority commensurate with the responsibilities delegated to him by the owning Division Director. The FM has the same authority as other line managers. The FM is given the following authority and responsibilities with respect to maintenance:

The Division Director has the ultimate authority for the assigned facilities.

- Approve any activities, or proposed changes to activities, that could affect the established facility operating limits;
- Control support and services personnel who perform functions for the facility to maintain the established facility operating limits, or the facility assets;
- Determine the facility operating limits through the hazard analysis process;
- Review, approve, and assess operations within the facility;
- Efficiently and effectively maintain the facility operating limits.
- Efficiently and effectively maintain the facility's structures, systems, and components capabilities and assets.

This LIR does not contain any requirements with respect to the training and qualifications of the Facility Manager to perform these tasks. FSS Division is in the process of developing an LIR that would stipulate the training requirements for the Facility Managers.

The LIR does not contain any requirements with respect to the training and qualifications of the Facility Manager to perform these tasks.

The Area Coordinator has the responsibility for corrective, preventative, and predictive maintenance. In fulfilling the responsibilities of the Zone Team Leader, the Area Coordinator provides technical leadership and advice to the Facility Coordinator on proper operations and maintenance activities for the facility structure, systems and components as well as the design and development of the MEL in collaboration with the Facility Coordinator and the FM. Periodic walkthroughs of the NIS Division facilities are required to monitor the effectiveness of the operations and maintenance program.

The Area Coordinator has the responsibility for corrective, preventative, and predictive maintenance.

The Facility Coordinator is a member of the FMU team. Under the direction of the FM, the Facility Coordinator inspects the buildings and surrounding grounds for problems and oversees the maintenance and checking of facility support systems.

The Facility Coordinator oversees the maintenance of facility support systems.

The LANL Facility Engineering Services Group (FSS-9) has developed a job position entitled Facility Engineer which is optional for the FMU to use. FMU-75 does not utilize this position. The Facility Engineer is accountable to the FM for defining the performance, operating and maintenance criteria, and standards for assigned facility structures, systems and components; providing the technical expertise to support the efficient and effective long-term operation or use of the assigned structures, systems and components; and providing consultation to tenants and the LANL institution regarding performance capabilities, operational capabilities and condition of their assigned structures, systems and components.

The Facility Engineer which is not utilized by FMU-75 is accountable for maintenance criteria.

2.4.3 Occurrence Reporting and Lessons Learned

Occurrence Report ALO-LA-LANL-RADIOCHEM-1996-0007, discovery date January 2, 1996, resulted in a corrective action to raise the setpoint that controlled dampers to close. This corrective action was developed as an additional precaution to address a freeze protection issue. The effectiveness of the controlled dampers, which closed as designed for this occurrence when the temperature reached between 40 and 45 degrees Fahrenheit, was evaluated. The setpoint of the damper controls was raised to between 50 and 55 degrees Fahrenheit. The corrective actions to this event were limited to TA-48-1 and this specific piece of equipment. There were no institutional corrective actions for this event.

During the week of December 16-20, 1996, LANL experienced subfreezing temperatures that resulted in a series of freeze protection events that were "rolled-up" into occurrence report ALO-LA-LANL-1996-0007. The events were categorized as a reportable occurrence on December 19, 1996. The notification report for these events was submitted to the ORPS system on December 23, 1996. The final report was not submitted to ORPS until October 30, 1997. This exceeds the 45 day limit set by DOE Order 232.1, *Occurrence Reporting and Processing of Operations Information*, for submitting final reports. Through the DOE/UC contract, DOE has recognized that finalization of occurrence reports in the 45-day limit is a problem. During the last performance period, LANL did not meet expectations and issued a final report within 45 days only 52% of the time.

Subfreezing temperatures resulted in a series of freeze protection events on December 16-20, 1996.

In addition to not meeting the 45-day limit, finalization of the report in time to address seasonal considerations was not accomplished. The stated corrective actions (2 & 3) were not completed until September 30, 1997, and October 22, 1997, respectively. This did not allow for adequate implementation prior to the onset of cold weather in the Los Alamos area.

The root cause of these occurrences was determined to be a management problem—policy not defined, disseminated or enforced—since LANL did not have a freeze protection preventative maintenance standard to identify freeze protection measures. On October 22, 1997, FSS-9 issued a Freeze Protection Maintenance and Operations Standard (MO 3.7-600). This standard requires each FMU to prepare a freeze protection plan in accordance with DOE Maintenance Management program guideline, DOE Order 4330.4B, section 19.1. The M&O standard section 7.8 has a requirement to "Functionally test systems controlled by dampers." In September 1997, FSS-9 distributed a monthly news bulletin, "FSS-9 Maintenance Talk," to all facility managers and area coordinators throughout LANL providing basic freeze protection recommendations. This newsletter specifically referred to protecting coils, citing that heating/cooling coils in duct systems have a strong vulnerability to freeze damage. It stated that damper

The root cause of the occurrences was determined to be a management problem.

actuators should be tested. The FM for TA-35, Building 27 as well as the Area Coordinator were on the distribution list for this newsletter. Further, there has been no Laboratory follow-up to ensure that these lessons learned/good practices are implemented at an individual facility.

Other reminders have been issued with respect to freeze protection. The LANL Operating Experience Weekly Summary, Issue 97-19, September 6-19, 1997, included an article on freeze protection called "Fall Means Freeze Protection." The article refers to the fact that since 1990, LANL has experienced 31 reportable freeze protection incidents. The DOE "Operating Experience Weekly Summary", Issue 97-42, October 10-16, 1997, contained an article on Freeze Protection Reminder and Severe Weather Planning. In addition to the regular distribution for this document, the AL Maintenance Program Manager forwarded the article to AL sites/facilities on November 4, 1997, to remind them to review or establish their Freeze Protection Programs.

2.4.4 Chilled Water and Sump System Condition and Maintenance

A Condition Assessment Survey (CAS) inspection was performed at TA-35, Building 27 on June 6, 1997. The report revealed that CWE-1 failed mechanically with the following deficiencies: "worn out, cabinet leaking, and the spray headers 70% plugged." A work ticket was issued to repair these deficiencies before the formal results of the inspection were issued to the FMU; the work was completed in August 1997. The sump pumps, PS-1 and PS-2, were listed as poor. Poor and fail grades under the CAS indicate a need for imminent or immediate replacement. CWE-1 was slated for replacement. At the time of the incident, some replacement parts such as heat exchangers were on-site. However, there was no evidence of any formal replacement schedule.

On June 6, 1997, an inspection revealed that CWE-1 failed mechanically.

On June 6, 1997, an inspection revealed that the sump pumps were in poor condition.

An equipment history report revealed that the following work was performed on the equipment involved in this incident. CWE-1 had preventative maintenance for lubrication on April 16, 1997 and October 20, 1997. No history was listed for the replacement of the spray heads in August 1997; however, the Area Coordinator and pipe fitters verified this was performed. PS-1 and PS-2 were lubricated on April 16, 1997, and PS-1 was additionally lubricated on October 20, 1997.

The Area Coordinator provided to the Board a copy of a "PM checklist all facilities" dated December 2, 1997, which retrospectively captures the normal checks within FMU-75. With respect to the systems associated in this event, the following checks are pertinent:

<u>CWE-1 Unit</u>

- Check level of water treatment chemical barrels daily
- Check water treatment concentrations and adjust as necessary - weekly

<u>Building 27 Mechanical Room</u>

- Walk-through building mechanical rooms - weekly
- Conduct the following every Spring and Fall:
    - Check thermostat operation and repair, calibrate and replace as necessary
    - Check temperature controller operations and repair, calibrate and replace as necessary
    - Check boiler system low limit controls, check and calibrate in the Fall only
    - Check unit heaters in the Fall

2.4.5 Radiological Source Control

After the flood it was difficult to determine the precise inventory of sources on the sub-basement of Building 27. During the inventory process, NIS-5 found additional sources that had not been on the original inventory. This inventory and additional inventory checks took time and made it difficult to establish the 100% source inventory early in the response to the flood.

After the flood it was difficult to determine the precise inventory of radiological sources on the sub-basement of Building 27.

Sources stored in the sub-basement "cage" were placed on shelves and were washed away by the flooding. Moreover, one or several of the sources were physically damaged when boxes and other material were moved in the cage during the flood clean-up. This problem applied only to small sources. Larger sources were effectively stored in polyethylene shielded containers and Type B containers.

NIS-5 has accumulated a large source and material inventory. Much of this inventory is in poor condition and is no longer used. Prior to the flood, NIS-5 initiated a program to locate, inventory, and dispose of all the legacy material that was either unused or in poor condition. A large quantity of this legacy waste material had been removed from the sub-basement of Building 27.

A large quantity of this legacy waste material had been removed from the sub-basement of Building 27.

The waste removal process had proceeded significantly toward completion. At the time of the flood, the entire ensemble of NIS-5 legacy waste (sources and radioactive material) had been identified, inventoried, and staged on the first floor of Building 27. Some 700 items were identified.

2.4.6 Surveillances

Remote

Institutionally LANL has a system to remotely monitor the functionality of key pieces of equipment. It is at the discretion of the FM to determine what equipment is placed on this system. Currently there is no guidance recommending what should be placed on this system. However, at other facilities, sumps are remotely monitored to give an indication of high level alarms. At Building 27, facility personnel stated that the only equipment they have on the monitoring system is their boilers.

LANL has a system that remotely monitors key pieces of equipment, however, it was not being used in Building 27

Physical

The FMU conducts regular walkthroughs of the facilities; however, there are no established criteria for conducting the walkthroughs as well as checking operating parameters. The Area Coordinator did develop a listing after the incident of normal checks within the FMU. These walkthroughs are not documented.

FMU conducts regular walkthrough, however, no criteria have been established for conducting them.

FSS-9 Facility Engineering Services

The role of FSS-9 is to provide institutional guidance and measure FM performance with respect to facility management, maintenance management, and facility engineering. An additional role is to provide centralized services such as configuration management, planning, and record storage. In 1994, the FMUs were created and in 1995 the FMs were given the responsibility and funding to perform maintenance for the facility. Prior to this, FSS-9 coordinated and was responsible for maintenance. The

FSS-9 is responsible for providing institutional guidance and review FM performance.

M&O Standards were developed from the knowledge of JCNNM and FSS-9 to provide FMs with procedures to perform maintenance. The M&O Standards are not requirements. However, FSS-9 is in the process of developing a LIR that will require FMs to follow certain elements of the M&O Standards that are supported by the work smart standards. FSS-9 gathers data to reflect the performance of FMs; however, the performance measures do not accurately depict performance. The Division Director is responsible to hold the FM accountable for following the requirements. FSS-9 has identified that FMUs need a better ways of ensuring maintenance is performed, and FSS-9 needs a better way to measure performance.

DOE

DOE LAAO has assigned FR coverage to TA-35; however, the FR who is assigned to the area is not yet qualified. The individual is currently assigned to completing his qualification card for phase one to become provisionally qualified to perform FR duties. The FR does perform periodic walkthroughs of TA-35 for orientation as well as to accomplish qualification tasks.

DOE LAAO management has indicated that due to staffing changes oversight of the maintenance management program has decreased. Formerly, the FR for TA-35 and a support contractor provided coverage for institutional oversight of the maintenance management program. Currently, LAAO has a support contractor to cover oversight of maintenance management programs at LANL. The current individual is newly assigned (less than six months) and is not cleared to visit all facilities at LANL. DOE AL has one person, the program manager, to oversee maintenance programs throughout the AL complex.

Due to LAAO staffing reductions, DOE maintenance management program oversight has decreased.

DOE LAAO has Standing Instructions defining the responsibilities of the Facility Representatives. Semiannually the Occurrence Reporting Program is reviewed to appraise the facility's programs for investigating abnormal events. In addition the FRs have the responsibility to follow up and review occurrence reports. The FR reviews and assesses occurrence reports for facilities under his cognizance. The final occurrence report is reviewed to verify accuracy of the factual information, validation of root causes, adequacy of corrective actions, timeliness of scheduling the corrective actions, and adequacy of lessons learned. The FR also ensures that lessons learned and generic or programmatic implications are identified and elevated to the Assistant Area Manager for Facility Operations, as well as ensuring that contractor actions are taken to prevent recurrence. However, the Standing Instructions do not address how institutional occurrence reports are to be handled through this process to ensure that corrective actions are performed and are effective in preventing recurrence.

2.5 ACCIDENT ANALYSIS

An investigation of the operating conditions of the key components of CWE-001 was conducted on December 1, 1997. It was found that the key components were all in working condition.

It was found, however, that the activation spring in the pressure switch associated with pump PCW-11 was broken, allowing flow to the emergency "feed and bleed" system through valve V-1. Further analysis of the pressure switch found that the setpoints were 22 psi and 30 psi (i.e., if pressure on the outlet side of the pump dropped below 22 psi, V-1 would open; when the pressure was re-established above 30 psi, V-1 would close). Subsequent inspection of the pressure switches noted that the activation spring for the PCW-12 pressure switch was also broken. However, PCW-12 was not operational at the time of the event.

The pressure switches were broken allowing the emergency "feed and bleed" system to operate.

An operational test of PCW-11 showed an outlet pressure of 22 psi. It is postulated that that since the operating pressure of this pump was right at the pressure switch setpoint, any pressure fluctuation in drawing water from TCW-1 would activate the pressure switch, thus opening V-1. If the system operated correctly, the resulting surge of pressure coming off the industrial water line, which normally operates at approximately 100 psi, would backflow toward PCW-11, thus closing the check valve located near the pump's outlet. In this situation the water around the coils would become stagnated.

Water was stagnant in the chiller coils.

Only when the pump would start "deadheading" against the closed check valve would the pressure increase enough to surpass the 30-psi reset point, thus closing V-1 and returning the system to normal operation. The deadhead pressure of the outlet side of PCW-11 as tested was 90 psi.

In the case of the incident, it is postulated that the operational outlet pressure dipped under 22 psi, thus opening V-1. The resulting surge caused the pump to "deadhead," thus increasing pressure in the outlet due to the closure of the check valve downstream of the pressure switch. However, the pressure switch never reset because the spring activator had broken. Therefore, the pump continued to run and V-1 remained opened with the system coming into a pressure equilibrium within the coils. This equilibrium essentially stagnated the water in the coils while the brunt of the industrial water pressure was being vented out of TCW-1's overflow pipe (path of least resistance).

The temperature sensor measures water basin temperature. The dampers did not close because the temperature sensor was set at 32 degrees Fahrenheit. The reason that the dampers were closed during the initial inspection of CWE-1 was because of the power being shut off to the building. A test was conducted during the Board's investigation to determine if the dampers operated properly. When the power was restored to the unit, the dampers opened because of the 32 degree Fahrenheit setting. When the power was shut off again, the dampers closed. Eventhough one vane of the damper outlet was found broken, this had no bearing on this accident. The temperature sensor measures the temperature of the coil spray system reservoir at the bottom of CWE-1. Given that the reservoir is out of the direct inlet path of the cold air, receives makeup water from the industrial water system, and is constantly being recirculated, it is unlikely the temperature would drop below 32 degrees. With the 3-degree operating band for the temperature controller, a temperature below 30 degrees would have to be achieved to close the dampers. Therefore, the coils were exposed to the outside air at a temperature of approximately 11 degrees Fahrenheit during the nights of November 14 and 15, 1997. The freezing of the stagnated water caused the coils to rupture.

The dampers did not close because the temperature sensor was set at 32 degrees Fahrenheit.

Once the breakage occurred, the pressure from both PCW-11 and from the industrial water system was relieved, thus explaining why the TCW-1 overflow only flowed for a short time and why PCW-11 did not experience any thermal damage due to cavitation and/or deadheading. The resulting water flow easily surpassed the capacity of the floor drain located near the unit. Additionally, the mechanical room floor was sloped toward the stairwell to the bottom floor.

The resulting water flow easily surpassed the capacity of the floor drain located near the unit.

The sump system on the bottom floor has two sump pumps, PS-1 and PS-2, which alternate in a first-stage configuration and then simultaneously if water reaches a second stage point as determined by a float in the sump pit. As a result of the sub-basement flooding, the water continued to rise in the pit bringing the float to the second stage. However, the second pump was never activated because the shroud protecting the float activated switches was slightly skewed at an angle and bound the switch activator before it could reach the second stage (Figure 12). The flooding was more than one pump could handle. The single pump configuration could handle approximately 80 gallons/minute; the flow during the event is estimated at 200 - 250 gallons/minute. The pumps continued to switch on and off but never came on simultaneously due to the bound actuator. The two-pump configuration could handle approximately 220 gallons/minute as demonstrated by post-incident testing. Eventually the water reached the electrical controllers of the sump pumps, which caused them to shut down. This ultimately lead to the 58½ inches of water found on November 17, 1997.

The second pump was never activated because the shroud protecting the float activated switches was slightly skewed at an angle and bound the switch activator before it could reach the second stage.

2.6 BARRIER ANALYSIS

The Board identified numerous barriers between the chilled water system and sump pumps and the initiating freezing temperatures. These barriers included physical barriers, management barriers, and administrative barriers, which are presented in tabular form in Table 1. Appendix B provides the details of this analysis.

The physical barriers that failed or were not in place were the dampers, sump pumps and notification system. Since the temperature sensor was set at 32 degrees, the dampers remained open allowing the chiller tubes to freeze and resulting in the water flowing to the sub-basement level. The sub-basement filled up with water because the second stage of the sump pumps did not operate. The activator arm for the second stage was bound on the shroud. Since there was no notification alarm in place, management was not aware of the 1st stage sump activation and of the flooding condition.

The management barriers that failed or were not in place were an institutional lessons learned program, roles and responsibilities, maintenance categorization, and oversight.

Figure 12: Actuator arm for sump pumps

There were eight freeze protection incidents which occurred in the previous year; however, the corrective actions were delayed until late fall. One corrective action was to develop a freeze protection standard; however, LANL and LAAO did not ensure that this freeze protection standard was in-place institutionally.

Although the FMU walked through the facility, no one was specifically assigned to look at the operations of the involved mechanical systems. There were operational parameters for components of the chilled water system, but the FMU did not ensure that the equipment was operating within these parameters. In fact, the switches to the pumps were broken and resulted in the stagnant water condition and the resultant tube freeze.

Maintenance on this equipment was based on an established categorization basis. One criteria for the categorization is to determine the worst case scenario. But the scenario of flooding was not used in the categorization of equipment to ensure increased, formal maintenance. As a result maintenance activities did not prevent equipment breakdown. In addition, LANL and DOE did not provide oversight over the maintenance program to ensure compliance with its requirements and guidance.

The administrative barriers that failed or were not in place were the operations knowledge and procedures. Without the operations knowledge, proper maintenance, testing and surveillances were not performed effectively. In fact, the incorrect setting of the temperature sensor was not found during the walk walkthroughs by the FMU. The incorrect setting allowed the dampers to remain open exposing the tube bundle to freezing temperatures. Also, there were no procedures established for freeze protection plans or for monitoring of equipment, such as sump pumps. These necessary documents were only issued as guidance to be used at the discretion of the FMU. Implementation of a freeze protection plan and monitoring of critical equipment could have mitigated, if not prevented, this incident.

Table-1 **Barrier Analysis Summary**

Freezing Temperature

Physical Barrier

- Notification Alarm
- Sump Pumps
- Damper

Management Barrier

- Oversight
- Categorization
- Roles and Responsibilities
- Lessons Learned

Administrative Barriers

- Operations Knowledge
- Procedures

Chilled Water System and Sump Pumps

2.7 CAUSAL FACTORS

The direct cause of the accident was the improper setting of the reservoir temperature sensor, which caused the dampers to remain open. Thus, the cold air blew over the stagnant water in the chiller tubes. In addition to this direct cause, there were root causes (the fundamental causes that, if corrected, would prevent recurrence of this and similar incidents) and contributing causes (causes that, would not, by themselves, have prevented the accident but are important enough to be recognized as needing corrective action). An Event and Causal Factors Chart is depicted in Figure 13, and a tabular summary is presented in Table 2.

Root causes of the incident were:

- Lessons Learned Program does not ensure implementation institutionally and in a timely manner.
- The FMU was not knowledgeable of the operations of the mechanical system, therefore, surveillances were not effective.
- The roles and responsibilities for the FMU with respect to maintenance were not clear or understood.
- Oversight by LANL was not performed.
- Guidance rather than procedures and standards were provided to the FMU.

Contributing causes of the incident were:

- Maintenance categorization of the equipment was incorrect.
- Maintenance was not conducted on a more frequent basis.
- Legacy design features were not evaluated after the facility and mission changed.
- Oversight by DOE was not performed.
- Radiological source control program was not completely developed and implemented. It’s recognized that the source control program is not a contributing

Legend

Rectangles signify events
Ovals signify conditions
Diamonds signify the accident
LTA stands for Less Than Adequate

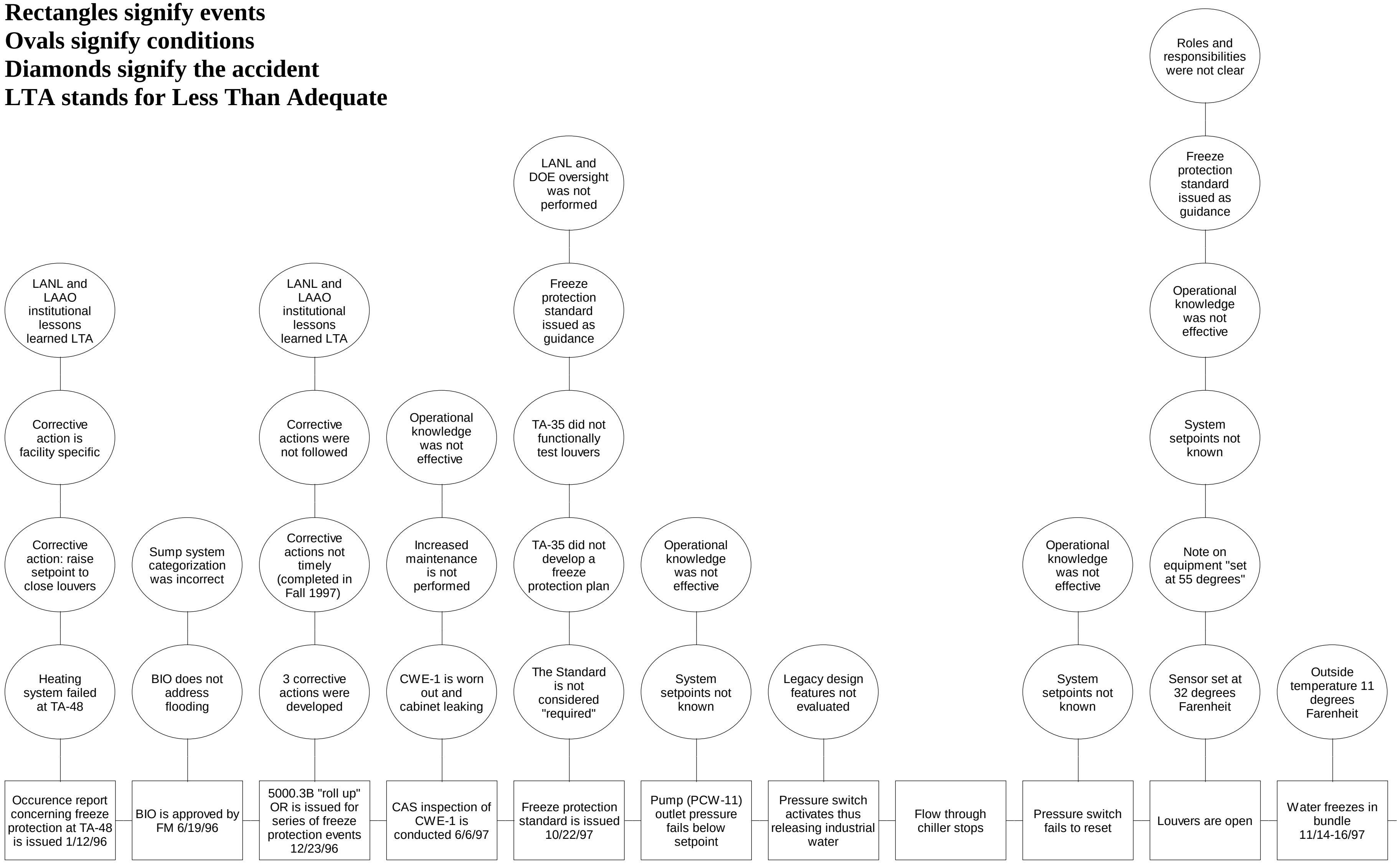
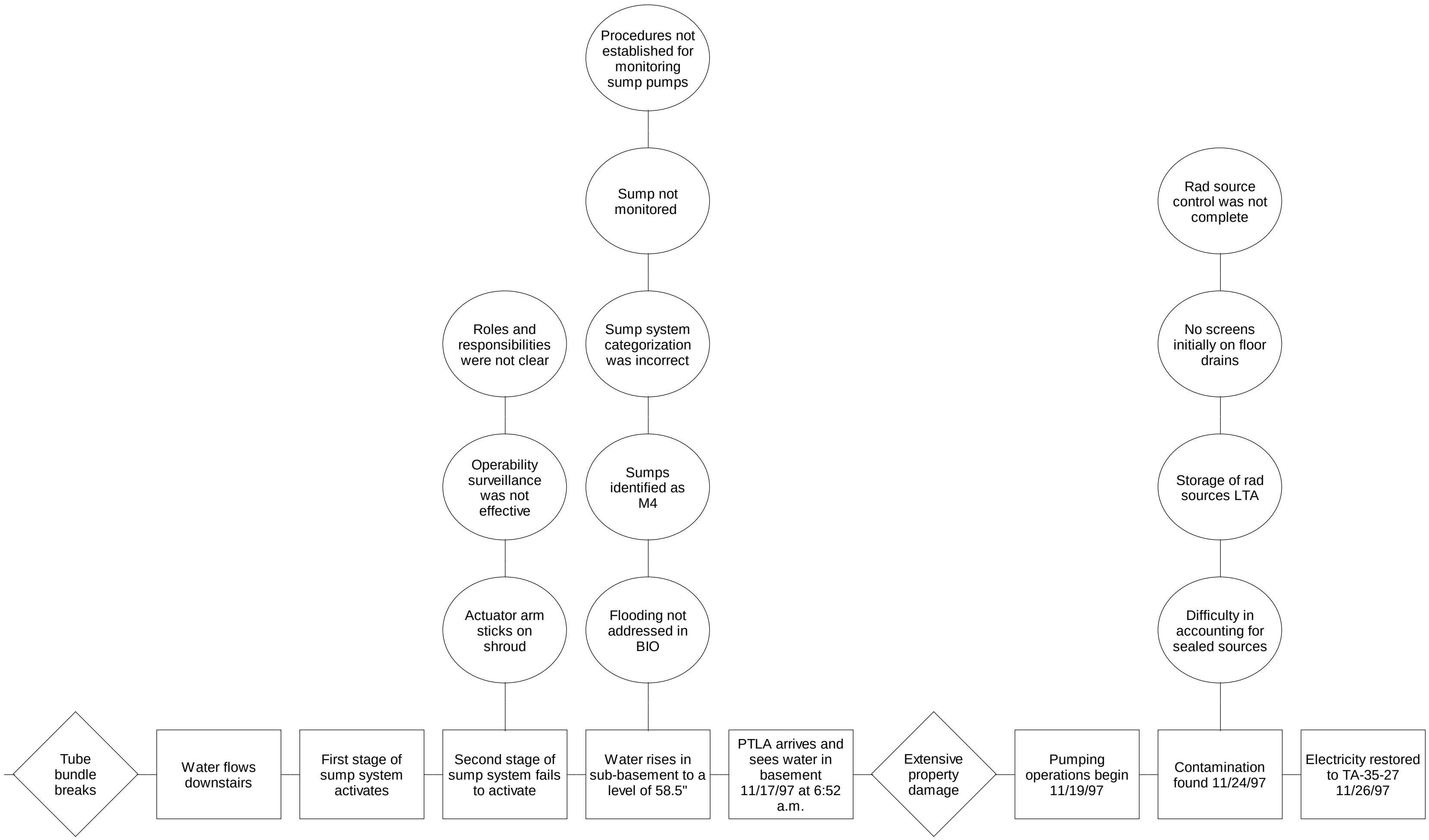


Figure 13: Events and Causal Factors Chart


Procedures not established for monitoring sump pumps
Sump not monitored
Sump system categorization was incorrect
Sumps identified as M4
Flooding not addressed in BIO
Roles and responsibilities were not clear
Operability surveillance was not effective
Actuator arm sticks on shroud
Rad source control was not complete
No screens initially on floor drains
Storage of rad sources LTA
Difficulty in accounting for sealed sources
Tube bundle breaks
Water flows downstairs
First stage of sump system activates
Second stage of sump system fails to activate
Water rises in sub-basement to a level of 58.5"
PTLA arrives and sees water in basement 11/17/97 at 6:52 a.m.
Extensive property damage
Pumping operations begin 11/19/97
Contamination found 11/24/97
Electricity restored to TA-35-27 11/26/97

cause to the rupture of the coils in CWE-1, however, this impacted the ability to respond to this incident.

Table 2 Summary of Events and Causal Factors

Root Cause	***Discussion***
Lessons Learned Program does not ensure implementation institutionally and in a timely manner.	In 1996, there were two Occurrence Reports, regarding nine separate incidents, related to freeze protection. In these reports corrective actions were established to prevent other freezing incidents. These corrective actions included developing a freeze protection program and raising the setpoint for dampers. The freeze protection plan was inadvertently issued as a guidance document. However, there was no follow-up by a responsible organization, to ensure implementation of the freeze protection plan. The corrective action also was not completed until late October 1997 when freezing conditions could occur. Corrective actions were not effective in preventing recurrence.
The FMU was not knowledgeable of the operations of the mechanical system, therefore surveillances were not effective.	Since the operational setpoints of the system were not known, the FMU team could not ensure that the systems operated properly when they conducted their surveillance or walkthroughs. Although the operational setpoint for the CWE-1 temperature sensor was written on the equipment, neither the FMU team members nor the maintenance personnel were knowledgeable of the parameters. In addition, operation of the pumps and pressure switches were not understood.
The roles and responsibilities for the FMU maintenance were not clear or understood..	The FMU did not establish clear and definitive roles and responsibilities. Therefore, no individual was responsible for checking operational performance and set points of the systems.
Oversight by LANL was not performed.	Although roles and responsibilities were established in various LIR and standards, no organization ensured that the FMU was

Root Cause	***Discussion***
	meeting the established roles and responsibilities and performance objectives.
Guidance rather than procedures and standards were provided to the FM.	The freeze protection M&O standard was issued as guidance. In addition, only a guidance document exists for categorizing equipment and maintenance. Since these standards are optional, effective and consistent maintenance activities are not performed. Had the FMU developed a freeze protection plan in accordance with the guidance provided, the dampers should have been functionally tested leading to resetting the temperature sensor from 32°F to an appropriate setting. There is no institutional procedure to require remote surveillance of important equipment such as the sump pumps. Although the second stage on the sump pump failed because the actuator arm was bound by the shroud, a sump alarm would have alerted the appropriate personnel of the condition and response would have limited the extent of the property loss.
Contributing Cause	***Discussion***
Categorization of the equipment was incorrect.	The sump pumps were identified as an M4 system. This categorization was incorrect since the basement area stored numerous sealed radiological sources vulnerable to water damage and the basement housed over three million dollars in assets.
Maintenance was not conducted on a more frequent basis.	Maintenance on equipment was minimal. Increased maintenance was not conducted based on history, potential failure and importance to mission.
Legacy design features were not evaluated after the facility and mission changes.	The initial design of the facility included a 2½ inch backup “feed and bleed” cooling system. When the chiller tubes failed, the 200 gpm flow overcame the first stage of the sump pump. The redesign or removal of this system would have reduced the amount of flood damage. DOE oversight was not performed.

Root Cause	*Discussion*
DOE oversight was not performed.	The reduction in staff and qualified individuals resulted in inadequate oversight of their institutional management maintenance program.
Radiological source control program was not completed. It's recognized that the source control program is not a contributing cause to the rupture of the coils in CWE-1, however, this impacted the ability to respond to this incident.	Three inventories had to be performed to ensure 100% accountability of all sources. The sources were stored on shelves and were washed away during the flooding and could have entered unscreened drains within the caged area. The sources became physically damaged as a result of the flooding and clean-up activities resulting in contamination. Some actions had been taken by NIS-5 prior to the flood; however, had actions been taken more aggressively some of the difficulties in response to the flood would have been avoided or minimized.

3.0 Conclusions and Judgments of Need

This section of the report identifies the conclusions and judgments of need determined by the Board as a result of using the accident analysis methods described in Section 1.4. Conclusions of the Board are those considered significant and are based upon facts and pertinent analytical results. Judgments of need are managerial controls and maintenance standards believed by the Board to be necessary to prevent or mitigate the possibility or severity of a recurrence of this type incident. Judgments of need flow from the conclusions and causal factors and are directed at guiding managers in developing follow-up actions. Table 3 lists the conclusions and the corresponding judgments of need identified by the Board.

Table 3 Conclusions and Judgments of Need

Conclusions	*Judgments of Need*
Application of lessons learned from freeze protection incidents was not effective.	LANL needs to ensure that institutional corrective actions are uniformly and promptly implemented. LAAO needs to establish a process to ensure important institutional corrective actions, based on lessons learned, are implemented at LANL.

FMU-75 did not develop a freeze protection plan and LANL did not ensure that a freeze protection plan was developed.	LANL needs to establish requirements for FMUs to develop freeze protection plans and ensure they are implemented at all FMUs.
FMU-75 did not take actions to protect TA-35, Building 27 sub-basement from a flood.	LANL needs to re-evaluate equipment categorization and "legacy design" for failure modes to prevent potential flooding. LANL needs to ensure operability of all safety equipment including sump pumps in the basement and sub-basement.
NIS-5 did not complete planned radiological source control actions which would have facilitated flood response and minimized flood damage.	NIS-5 needs to complete radiological source control and storage actions.
Institutional maintenance management program lacks clear requirements, training, and oversight.	LANL needs to evaluate current requirements or establish requirements for the categorization, maintenance, and surveillance of systems. Clear roles and responsibilities and associated training to provide understanding of both responsibilities and operations need to be developed. Evaluation of performance through oversight to these requirements, needs to be performed to provide institutional consistency and incorporation of shared corporate knowledge between FMUs. All FMs need to be held accountable for the operation of the facility.
The reduction in staff and qualified individuals resulted in inadequate oversight of the institutional management maintenance program.	DOE/AL and LAAO need to strategically align resources in order to provide oversight of the maintenance management program.

4.0 BOARD SIGNATURES

Rudy J. Valdez
Accident Investigation Chairperson
U. S. Department of Energy
Los Alamos Area Office

Date: 12/31/97

Ralph A. Fevig
Trained Accident Investigator
U. S. Department of Energy
Albuquerque Operations Office

Date: 12/31/97

Steven G. Fattor
Board Member
U. S. Department of Energy
Albuquerque Operations Office

Date: 1/5/98

Susan E. Mathews-King
Board Member
U. S. Department of Energy
Los Alamos Area Office

Date: 12/31/97

APPENDIX A

United States Government **ɔpartment of Energy**

memorandum

Albuquerque Operations Office

DATE: NOV 21 1997

REPLY TO
ATTN OF: OSHD (97016ger)

SUBJ: Establishment of an Investigation Team

TO: **Tom Todd, Area Manager, LAAO**

I hereby establish a Type B Investigation Board to investigate the property damage as a result of a chiller line rupture at TA-35, Building 27, Los Alamos National Loaboratory (LANL) on November 17, 1997.

The following individuals are appointed to the Team in the listed capacity:

Team Chairperson:	Rudy J. Valdez, Team Leader Environment, Safety and Health, Los Alamos Area Office (LAAO)
Trained Chairperson:	Ralph Fevig, Safety Engineer, Occupational Safety and Health Division (OSHD), AL
Team Members:	Susan Mathews-King, Facility Representative, LAAO Steve Fattor, Maintenance Program Manager, OMD, AL
Advisor:	Dennis G. McLain, Deputy Group Leader, FSS-9; LANL
Administrative Support:	Raquel Rodrigues, OSHD, AL

The Board will be assisted by advisors and consultants and other personnel as determined by the Chairperson.

The scope of the Board's investigation will include, but not limited to, identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the property damage; developing conclusions; and determining the judgments of need that, when implemented, reduce the probability of a similar recurrence. The investigation will be conducted in accordance with DOE Order 225.1 and will specifically address the role of DOE and contractor organizations and management systems as they may have contributed to the property damage. The scope will include the adequacy of the contractor's management system, maintenance practices and make any recommendations as appropriate.

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 the causal factors have been completed. Four copies of the draft report should be provided to me by December 23, 1997, for review prior to its preparation in final form. Any delay to this date shall be justified and forwarded to this office. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report. Following this authorization draft copies of the factual portion of the investigation report will be submitted to the contractor and operations offices for factual accuracy review prior to report finalization.

By copy of this memorandum, I am advising the supervisors of each of the Board Members that this assignment is full-time until the investigation and report are completed. The advisors to the Board shall assist the Board in the investigation on a priority basis and provide input to the chairman, as requested. Board Members and advisors are requested to attend an opening briefing to be held at LAAO, at 8:00 a.m. on November 24, 1997.

for Bruce G. Twining
Manager

cc
V. Reis, DP-1, HQ/FORS
T. O'Toole, EH-1, HQ/FORS
R. Staffin, DP-10, HQ/FORS
D. Miotla, DP-13, HQ/FORS
G. Podonsky, EH-2, HQ/GTN
D. Vernon, EH-21, HQ/GTN
D. Glenn, LAAO
K. Zamora, LAAO
J. Brown, LANL
R. Glass, OTMO, AL
G. Runkle, OSHD, AL

APPENDIX B

Appendix B Barrier Analysis

Barrier Type	Hazard	Direct Barrier or Control Failure	Possible Contributing Factor to Barrier or Control Failure	Possible Root Causes of Failure	Loss	Evaluation
Physical Barrier	Chilled Water Tubes Freeze	Properly running transport equipment	Setpoints of pressure switches were not verified nor known; pump performance deteriorated to low set point.	Aging and deterioration	CWE-001	With aging and deteriorating equipment, increased maintenance and surveillance is needed. The CAS report for Building 27 had identified the deteriorating condition of the CWE-001.
Physical Barrier	Chilled Water Tubes Freeze	Emergency feed and bleed system from the industrial water system	Emergency system valve could not be shut due to broken pressure switches. Industrial water equalized the pressure in the coil system resulting in no flow through the tubes.	Lack of maintenance, inadequate operational surveillance; and legacy design not suited for current operations	CWE-001	The FMU was not aware of the system operation and its setpoints; therefore, appropriate maintenance and surveillance activities were not established. The building was designed for a nuclear reactor and was not changed to accommodate the current tenant. The current facility houses offices, labs and training operations. The coil tubes did not have any pressure/drain valves, which resulted in the stagnation of water.
Physical Barrier	Chilled Water Tubes Freeze	Backup pump and pressure switch	The other pressure switch was broken and there was no automatic switching gear for backup pump.	Lack of maintenance, inadequate operational surveillance, and inadequate design	CWE-001	The FMU was not aware of the system operation and its setpoints; therefore, appropriate maintenance and surveillance activities were not established
Physical Barrier	Chilled Water Tubes Freeze	Temperature sensor	System had no freeze stat on the inlet air.	Legacy design not suited for current operations	CWE-001	Without a freeze stat, there was reliance on the basin temperature sensor and operational surveillances.
Physical Barrier	Chilled Water Tubes Freeze	Dampers	Dampers remained open due to the 32°F sensor setting allowing 11°F air to blow over the coils.	Unauthorized/ inadvertent change of temperature setting.	CWE-001	The temperature sensor was not secured from individuals making unauthorized or inadvertent changes.

Barrier Type	**Hazard**	**Direct Barrier or Control Failure**	**Possible Contributing Factor to Barrier or Control Failure**	**Possible Root Causes of Failure**	**Loss**	**Evaluation**
Physical Barrier	Chilled Water Tubes Freeze	Wall thickness of copper coils	Expansion of water breaks tubing.	Pressure buildup by ice exceeds design capacity of the copper coils	CWE-001	There was an initial concern that the tubes were also deteriorated but it was found that the tubes were replaced three years earlier.
Physical Barrier	Basement Flooding	Sump system	1st Stage, one pump operation is overcome and 2nd stage, two pump operation does not activate due to activator arm bound on float shroud.	Inadequate operational surveillance and inadequate design	Water damage	Better method was needed to secure shroud rather than using one hose clamp. Also, the sump was identified as M4 rather M3, which would have required a more rigorous approached to maintenance.
Physical Barrier	Basement Flooding	Notification alarm	Neither the sump nor the operability of the CWE-01 is remotely monitored.	Inadequate design and ineffective policy and procedures	Water damage	Installation of a notification alarm would have mitigated the incident since the incident occurred over the weekend. However, there are no requirements established to require notification alarms although there was a high property value located in the sub-basement.
Management Barrier	Chilled Water Tubes Freeze and Basement Flooding	Direct supervision of maintenance	No one makes effective operational surveillances on the equipment.	Roles and responsibilities not clear and lack of operational surveillance	CWE-001 and water damage	The roles and responsibilities were unclear; as a result, all members of the FMU walked through the facility but no one specifically was assigned to look at the operations of the system based on the institutional guidance. The FMU was not fully knowledgeable of the operating parameters of the systems and therefore could not perform adequate surveillances. Although the FMU conducted walkthroughs of the equipment areas, they did not notice the improper setting of the temperature sensor or the float arm being bound by the shroud.
Management Barrier	Chilled Water Tubes Freeze and Basement	Categorization of equipment based on risk assessment	The equipment was categorized M-4 rather than M-3.	Policies and procedures not clearly defined	CWE-001 and water damage	In determining the categorization per the institutional guidance, the worst-case failure mode, the operating history

Barrier Type	Hazard	Direct Barrier or Control Failure	Possible Contributing Factor to Barrier or Control Failure	Possible Root Causes of Failure	Loss	Evaluation
	Flooding					and the insufficient maintenance were not considered; therefore, an unanalyzed event (flooding) occurred.
Management Barrier	Chilled Water Tubes Freeze and Basement Flooding	Conduct of maintenance	FSS-9 establishes policy and procedures.	No oversight to ensure compliance with policies and procedures	CWE-001 and water damage	There is no evaluation of the FM performance to the institutional maintenance guidance; therefore, the FMs are not accountable for proper maintenance.
Management Barrier	Chilled Water Tubes Freeze and Basement Flooding	Lessons learned	Institutional freeze protection corrective actions were not effective.	Lessons learned ineffective	CWE-001 and water damage	Although required to prepare a freeze protection plan and functionally test dampers, there was no follow-up to determine effective implementation of these corrective actions. Also, the seasonal timeliness of the corrective actions caused delay. The corrective actions for institutional lessons learned are not tracked to closure by the FR as are facility corrective actions. As a result, LAAO did not ensure that the freeze protection plan was instituted LANL-wide.
Management Barrier	Chilled Water Tubes Freeze and Basement Flooding	FM oversight	FMs operate without any feedback to performance	No oversight to ensure compliance with policies and procedures	CWE-001 and water damage	Without accountability, FMs are free to operate independently and inconsistently.
Management Barrier	Chilled Water Tubes Freeze and Basement Flooding	DOE oversight of Maintenance Management	DOE/AL and LAAO staffing changes has reduced maintenance management oversight as well as the number of qualified individuals performing oversight.	Reduced DOE oversight to ensure compliance with policies and procedures	CWE-001 and water damage	The reduction in staff and qualified individuals resulted in inadequate oversight of their institutional maintenance management program.
Administrative Barrier	Chilled Water Tubes Freeze and Basement Flooding	Procedures/ instructions	No FMU directed procedures; FSS procedures are established as guidance.	Inadequate/ inconsistent maintenance	CWE-001 and water damage	If there are only guidance documents, there is little consistency in the conduct of maintenance across the Laboratory.
Administrative Barrier	Chilled Water Tubes Freeze	Maintenance History	Maintenance history is not documented and used for decision-	Inadequate/ ineffective	CWE-001 and water	If the maintenance history showed increased maintenance and

Barrier Type	Hazard	Direct Barrier or Control Failure	Possible Contributing Factor to Barrier or Control Failure	Possible Root Causes of Failure	Loss	Evaluation
	and Basement Flooding		making or maintenance strategy.	maintenance	damage	deterioration, then decisions could be made to replace or monitor more frequently the affected equipment.
Administrative Barrier	Chilled Water Tubes Freeze and Basement Flooding	Operator system knowledge	Equipment was not operated within the design parameters.	Inadequate operations and maintenance strategy	CWE-001 and water damage	Without the operations knowledge, proper maintenance, testing, and surveillances can not be performed effectively. Also, if the FMU had been aware of the important thermostat setting for the dampers, the thermostat could have been secured or at least monitored on a frequent basis to ensure the 55°F set point.
Administrative Barrier	Chilled Water Tubes Freeze and Basement Flooding	Training	Roles and responsibilities as well as system operability were not understood by the FMU.	Lack of formal training program	CWE-001 and water damage	With adequate training, the FMU could have developed necessary maintenance and operations procedures, especially in the area of operating condition surveillances. Inadequate and ineffective training resulted in a lack of maintenance and operations understanding.