ORNL/TM-2003/267

Report of the Investigating Team for the October 6, 2003, Radiological Event at Building 2026

November 2003

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REPORT OF THE INVESTIGATING TEAM FOR THE OCTOBER 6, 2003, RADIOLOGICAL EVENT AT BUILDING 2026

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ACRONYMS AND INITIALISMS

ALARA	as low as reasonably achievable
BJC	Bechtel Jacobs Company
BVLLLW	Bethel Valley Low level liquid waste
CAA	Cell Access Area
CAAM	Continuous Alpha Air Monitor
CDE	Committed Dose Equivalent
CSD	Chemical Sciences Division
DRCO	Division Radiological Control Officer
EAL	Emergency Action Level
EPA	Environmental Protection Agency
FS	Facility Supervisor
GI	generator interface
HEPA	high efficiency particulate air
HP	health physicist
INPO	Institute of Nuclear Power Operations
LLLW	low level liquid waste
LLW	low level waste
LPD	Laboratory Protection Division
LSS	Laboratory Shift Superintendent
M&C	Metals & Ceramics
MJR	Maintenance Job Request
MOU	Memorandum of Understanding
NM	Nuclear Materials
NMC&A	Nuclear Materials Control and Accountability
NNFD	Nonreactor Nuclear Facilities Division
NSTD	Nuclear Science and Technology Division
ORNL	Oak Ridge National Laboratory
OSSD	Operational Safety Services Division
PCB	polychlorinated biphenyl
PCM	Personal Contamination Monitor
POD	Plan of the Day
PPE	Personal Protective Equipment
R&D	Research and Development
RCO	Radiological Control Officer
RCT	Radiological Control Technician
RER	Radiological Event Report
RMAL	Radioactive Materials Analytical Laboratory
RSS	Research Safety Summary
RWP	Radiation Work Permit
SAR	safety analysis report
SBMS	Standards-Based Management System
SOP	standard operating procedure
TCLP	Toxicity Characteristics Leaching Procedure
TEDE	Total Effective Dose Equivalent
TRU	Transuranium Waste Program
TSR	Technical Safety Requirements
USQ	unreviewed safety question
WAC	waste acceptance criteria
WOCC	Waste Operations Control Center

EXECUTIVE SUMMARY

On October 6, 2003, in hot cell 1 of Building 2026, Chemical Sciences Division (CSD) personnel were conducting waste operations using manipulators to remotely denature, dilute, and dispose of low level liquid waste (LLLW) into the Bethel Valley LLLW system. The waste contained plutonium and americium isotopes.

The denatured liquid was poured into a drain line fixed to an upper cell pan (visible from the hot cell window). The line, which passed through a lower pan (not visible from the hot cell window) and then into a waste storage tank located outside of Building 2026 (See Figure 1-1). This denatured liquid was flushed with about 5-gallons of process water. After this flush, process water in the hot cell was run for about 30 minutes at a flow rate of about 1 gallon/minute. The drain was partially plugged. As a result, the liquid filled the lower cell pan in one or more of the hot cells and then flowed under the cell doors into the cell access area (Room 120).

The spill in Room 120 was discovered after normal operating hours by the facility radiological control technician (RCT) during routine facility rounds. The cell access area is a designated contamination area. The facility supervisor and the RCT were attempting to contain the spill when the Continuous Alpha Air Monitor (CAAM) alarmed. Immediately after the CAAM alarmed, the RCT and the facility supervisor stopped work and exited the area. The RCT and the facility supervisor monitored themselves using the personnel contamination monitor (PCM-1B) and no contamination was found on these personnel. Nasal swabs were collected from the RCT and the facility supervisor, and these indicated a potential uptake had occurred.

During the initial response to the spill, facility personnel did not recognize the event as being abnormal. As a result, they attempted to clean up the spill using mops and a vacuum cleaner that was not equipped with a High Efficiency Particulate Air (HEPA) filter. The investigation team noted that, while the initial responses were not appropriate, they were not contrary to established procedural guidance. The spill response procedures were not specific enough to provide proper guidance.

The investigation team concluded that the direct cause of the event was an obstruction in the drain line that partially blocked the line causing liquid to back up in the line, into the lower cell pans, and overflow the lip of the lower cell pans onto the floor of Room 120.

The investigation team concluded that the root cause of the event was that management allowed a culture to exist where degraded equipment performance was known and accepted without investigation and correction.

The investigation team also concluded there were a number of contributing causes of the event, including design, communication, work control, and human performance.

The investigation team developed the following Judgments of Need to address the direct, root, and contributing causes of the event. The Judgments of Need are placed in three basic groups as follows:

<u>Physical Needs</u>

1. The drains from the hot cells need to be unplugged and maintained clear.
2. Means need to be developed to minimize the amount of foreign material that can enter a hot cell drain.
3. There needs to be a reliable mechanism to allow the hot cell technicians to monitor the liquid

level in the lower pans in the hot cells.

4. All open process drains in contamination areas needs to be identified and the acceptability of having them remain open needs to be evaluated.
5. The waste material stored in the hot cells lower pans needs to be removed and disposed of.
6. The function of the Building 2026 tank 1401 level instrumentation needs to be determined in order to ensure the configuration supports this function.

<u>Administrative Needs</u>

7. Spill response directives and guidance need to be consolidated and updated to accurately describe the process for identifying and responding to radiological spills.
8. The roles and responsibilities of the Laboratory Shift Superintendent, ORNL spill response team, radiological control technicians, and facility personnel need to be evaluated relative to radiological spills inside of buildings.

<u>Managerial Expectations</u>

9. Management needs to ensure that personnel understand that problems identified in nuclear facilities are required to be identified and documented. These items need to be prioritized with the involvement of all stakeholders based upon programmatic and safety risk.
10. Management needs to ensure that work control documents have adequate detail to address the specific scope of work, the associated hazards, and the controls.
11. Roles and responsibilities that are consistent amongst organizations working in Building 2026 need to be developed and promulgated.
12. Plan-of-the-Day (POD) meetings need to be modified to ensure that all required parties attend the meetings and that all work expected to be performed that day is documented and discussed in sufficient detail to understand and execute planned work and manage facility interfaces.
13. The practice of storing material in hot cells needs to be evaluated.
14. The control and use of vacuum cleaners (HEPA and non-HEPA) in nuclear facilities needs to be evaluated.

1.0 INTRODUCTION

1.1 EVENT DESCRIPTION

On October 6, 2003, in hot cell 1 of Building 2026, Chemical Sciences Division (CSD) personnel were conducting waste operations using manipulators to denature, dilute, and dispose of low level liquid waste (LLLW) into the Bethel Valley LLLW system. The waste contained plutonium and americium.

The denatured liquid was poured into a drain line fixed to an upper cell pan (visible from the hot cell window). The line, which passed through a lower pan (not visible from the hot cell window) and then into a waste storage tank located outside of Building 2026 (See Figure 1-1). This denatured liquid was flushed with about 5-gallons of process water. After this flush, process water in the hot cell was run for about 30 minutes at a flow rate of about 1 gallon/minute. The drain was partially plugged. As a result, the liquid filled one or more of the lower cell pans and then flowed under the cell door into the cell access area (Room 120). The spill was discovered after normal operating hours by the facility radiological control technician (RCT) during routine facility rounds. The cell access area is a designated contamination area. The facility supervisor and the RCT were attempting to contain the spill when the Continuous Alpha Air Monitor (CAAM) alarmed. Immediately after the CAAM alarmed, the RCT and the facility supervisor stopped work and exited the area. The RCT and facility supervisor were monitored using the personnel contamination monitor (PCM-1B) and no contamination was found on these personnel. Nasal swabs were collected from the RCT and the facility supervisor, and these indicated a potential uptake of radioactive material had occurred.

The RCT swabbed the immediate work area for transferable contamination and obtained an initial contamination smear of 100,000 dpm/las (large area smear). Supervision and facility management were then notified. Urinalysis was initiated for each worker and lung counts were performed on them. Initial screening indicated a potential for an internal dose.

1.2 FACILITY OVERVIEW

The Radioactive Materials Analytical Laboratory (RMAL), Building 2026, located at Oak Ridge National Laboratory (ORNL), is maintained by the Nonreactor Nuclear Facilities Division (NNFD) for research and development (R&D) and operations activities conducted at ORNL. The Chemical Sciences Division is the major user of the RMAL. The RMAL facility receives, stores, assays, and disposes of a wide variety of radioactive materials. Assay operations involve dissolutions, dilutions, separations, physical, chemical, and radiochemical examinations of individual samples. The RMAL provides a wide range of analytical chemistry and other R&D support, which includes inorganic, organic, and radiochemical analyses and non-analytical activities, such as medical isotope extraction. Thus, the RMAL CSD staff performs in-house R&D activities involving a broad range of physical, chemical, and radiochemical measurements on radioactive materials.

The RMAL facility was constructed in 1964 (additions added in 1966 and 1985) and consists of 22,600 sq. ft. of laboratory and office space dedicated to analytical chemistry of radioactive materials. The facility is equipped with special containment and ventilation systems to handle high levels of radioactivity in hot cells (high gamma dose fields) and in glove box systems (high levels of alpha). To mitigate cross contamination, the facility is also designed to handle lower levels of radioactivity in laboratories segregated from higher contamination levels. The facility is fully equipped to handle the packaging and disposal of radioactive solid waste.

1.2.1 Scope of Work

The RMAL was originally designed to support the processing and examination of spent reactor fuels, but its current missions focus on low hazard operations. Over the past fifteen years, the type of work supported by the RMAL has changed from handling high-dose spent fuels to mostly radioactive waste characterization in support of waste management, environmental management, environmental restoration, and decontamination activities. Therefore, based on the current and near future (10 years) types of operations performed in the RMAL, its safety analysis is only intended to support nuclear Hazard Category 3 operations. Operations under this classification provide the basis for a broad application of the graded approach the safety and hazard analysis discussed in the Safety Analysis Report.

1.2.2 Facility Structure

The RMAL facility is a two story block structure. The construction of the facility consists of steel framing for all load bearing walls with 12-in concrete blocks used for exterior walls and 8-in concrete blocks for most interior walls. High-density concrete was used in areas around the cell windows, which is where workers would spend most of their time performing routine activities.

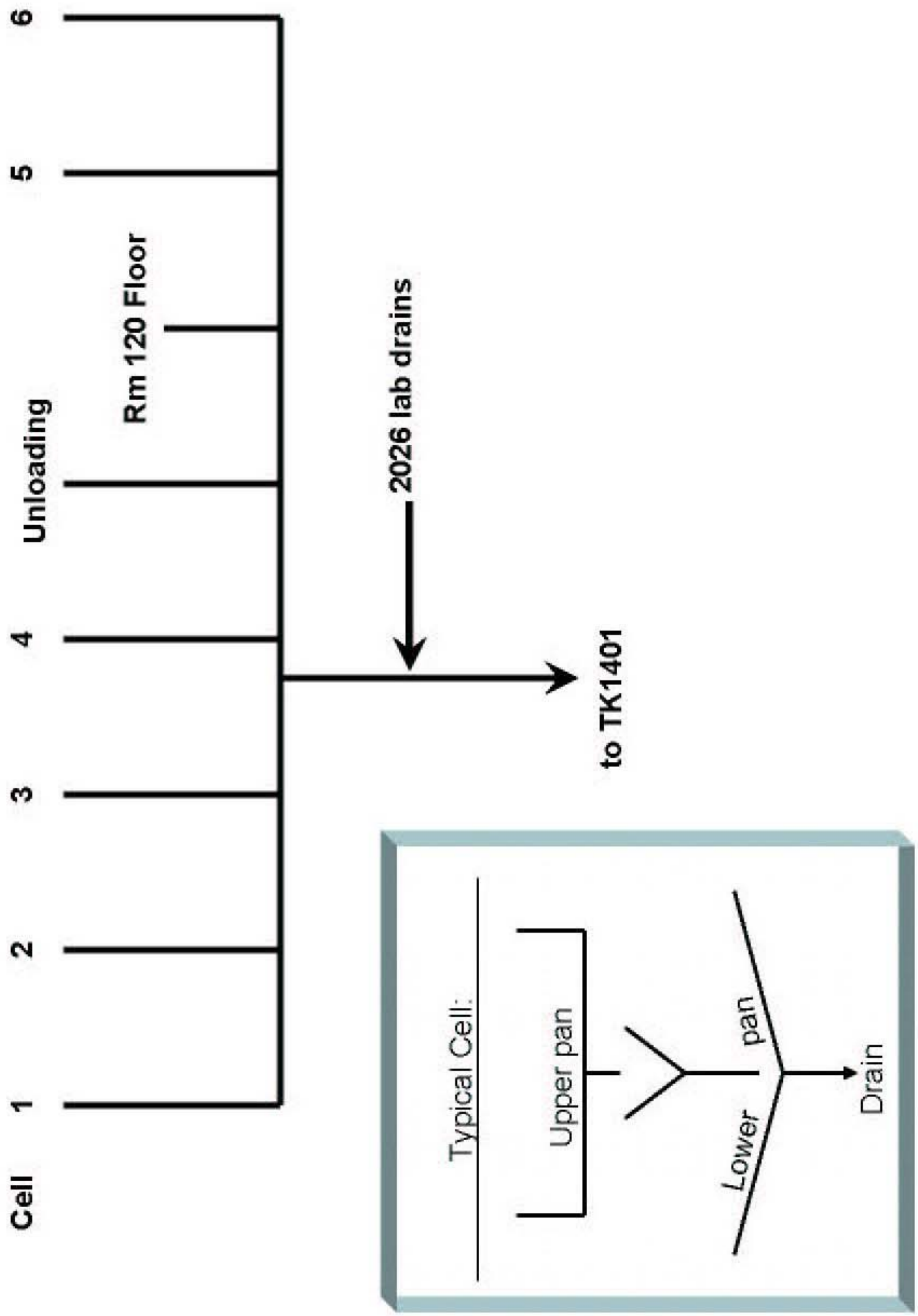
The RMAL facility can essentially be divided into six sections: (1) hot cell structures, (2) glove box laboratories, (3) radiochemical laboratories, (4) operating areas, (5) utility areas, and (6) office areas. Most of the office space and utility areas are located on the second floor of the facility. Simple floor plans of the first and second floor are shown in Figures 1-2 and 1-3.

1.2.2.1 Hot cells

The bank of hot cell includes six working cells (6 ft x 7 ft x 11 ft) with 51-in thick windows filled with concentrated zinc bromide, which provides shielding for up to 1400 Ci of ^{60}Co equivalent activity. One unloading cell is located in the center of the cell bank, and is equipped with a 2-ton hoist and a 5-ton pneumatic lift for handling shielded transport carriers used for radioactive samples. In addition, a large storage cell (8 ft x 12 ft x 8 ft) is located next to the loading cell, designed to handle up to 25,000 Ci of ^{60}Co equivalent activity of sample storage. Analytical capabilities of the RMAL include the ability to remotely manipulate high-dose levels from radioactive materials. The hot cells allow for remote handling of these materials via the utilization of slave manipulators within the shielded environment of the hot cell walls and windows. A variety of analytical techniques may be performed within the cells, which include inspection, separations, weight determinations, ion exchange, dissolutions, dilutions, and extractions.

1.2.2.2 Glove box laboratories

Radiochemical glove boxes exist in Labs 101, 133 and 136, as well as in the cell access area (Room 120). Glove boxes are painted carbon steel or uncoated stainless steel, and vary in length from three to six feet. All have inlet and outlet HEPA filters and are attached to a glove box exhaust system, which maintains a negative pressure in a range between -0.1 and -0.5 in/wg. Most boxes are equipped with an internal power strip and external fluorescent lighting. Access into and from the boxes is achieved via polyethylene sleeving attached to access ports that can be heat sealed.



Cell
1
2
3
4
Unloading
5
6
Rm 120 Floor
2026 lab drains
to TK1401
Typical Cell:
Upper pan
Lower pan
Drain

Fig. 1-1

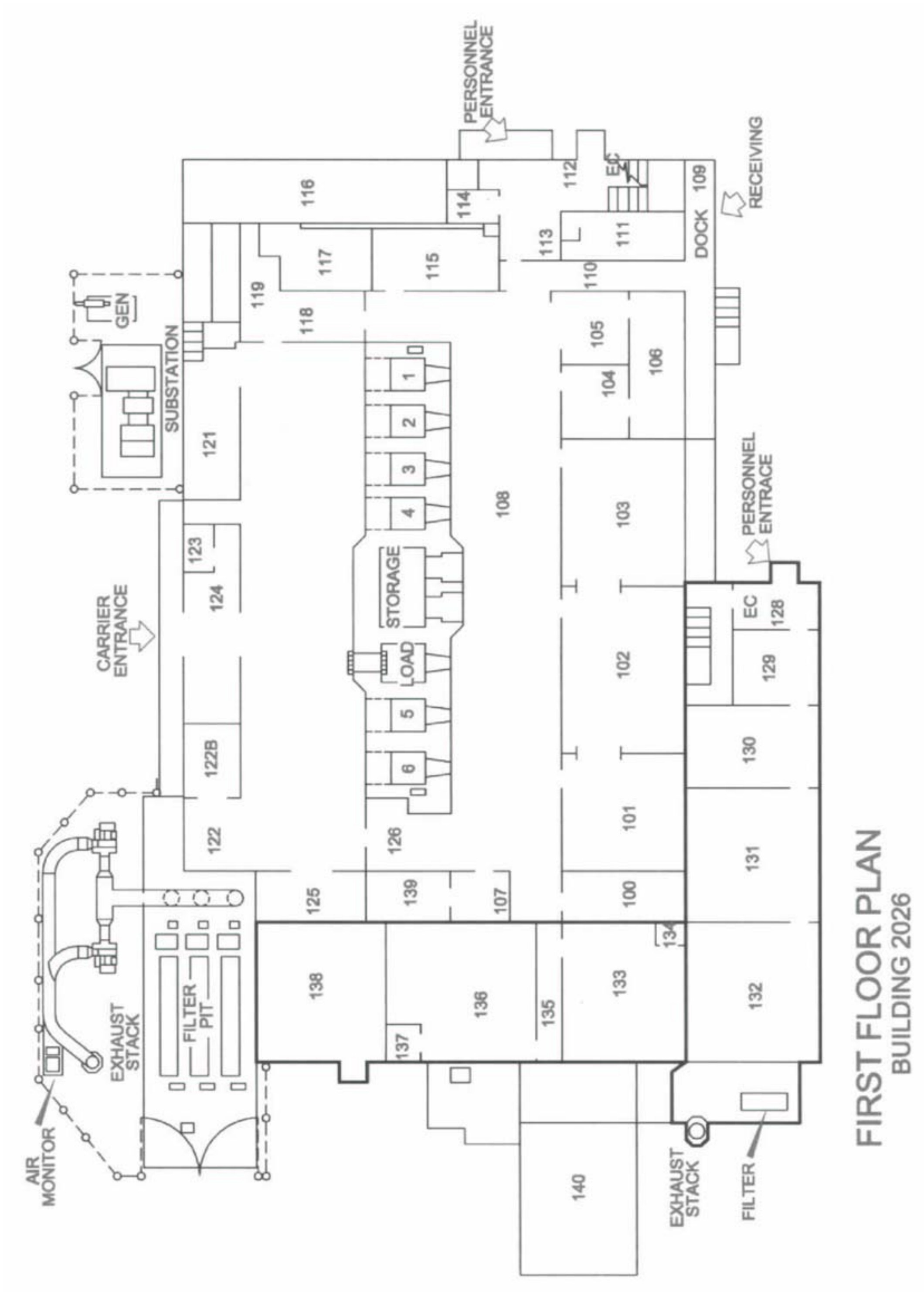


Fig. 1-2. First Floor Plan for the RMAL Facility

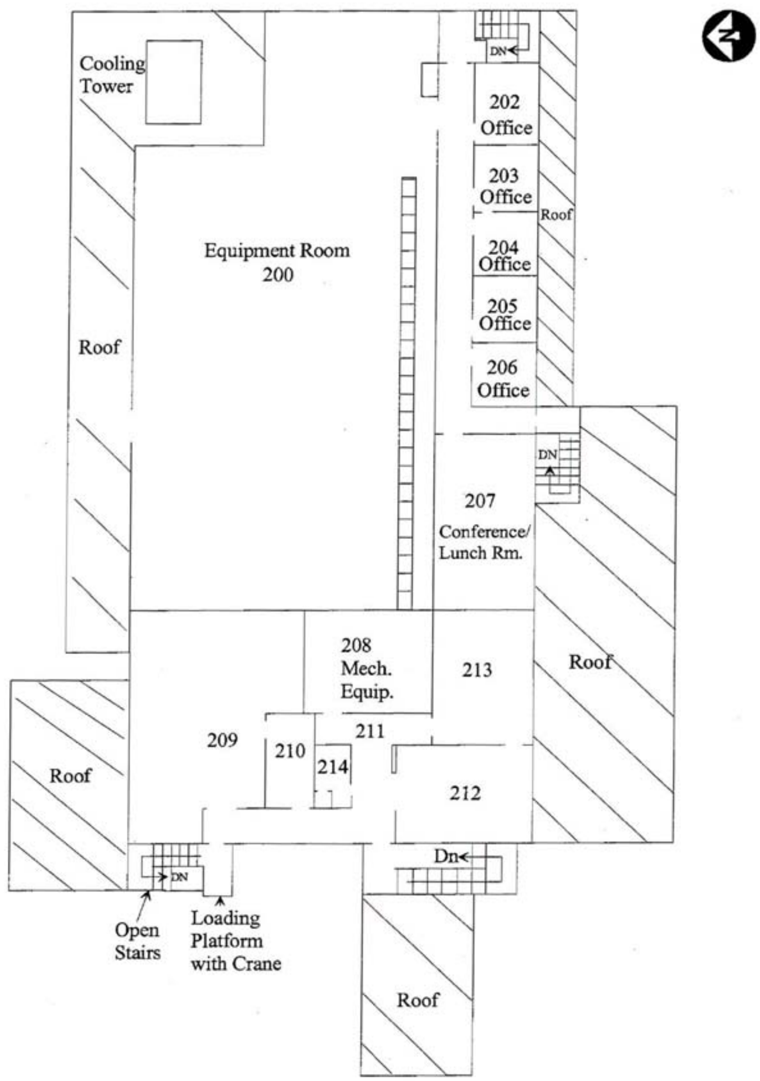


Fig. 1-3. Second Floor Plan for the RMAL Facility

1.2.2.3 Radiochemical laboratories

The RMAL analytical laboratory capabilities support a broad range of analytical methodologies required for testing and characterizing a wide range of samples, from mixed-radioactive sludge from underground storage tanks to spent fuel from a nuclear reactor. The facility is equipped with a variety of modern analytical instrumentation for the determination of metals, anions, organic compounds, radionuclides, physical properties, etc.

1.2.2.4 Operating areas

The laboratories and the cell operating areas are where the building personnel are normally located. Testing and analytical processes performed in the hot cells are conducted by personnel located in the cell operating area using master-slave manipulators. Various testing equipment, instruments and computers are located in the operating area to support analytical tests conducted in the hot cells.

1.2.2.5 Utility areas

The main utility area is on the second floor of the building in Room 200. This area contains the main power distribution panel, water and steam supply headers, hot water heater, ventilation control equipment, and various pumps and motors for the cooling tower and cooling systems. The air supply fans for the containment areas are also in the equipment area along with the ventilation fans for the office and change room areas (non-containment areas). A second utility area is located in the west end addition in Room 208 and a third utility area is located in the South addition in Room 130.

1.2.2.6 Office areas

Most of the facility office areas and the lunchroom are located on the second floor. These are well away from the radiological and chemical hazards.

1.3 REVIEW TEAM

As a result of the radiological release and personnel exposures on October 6, 2003, a review team was constituted via email on October 9, 2003, to conduct an investigation. On October 24, 2003, the review team was expanded and the investigation continued.

The review team was charged with evaluating the event, identifying contributing and root causes, and identifying appropriate recommendations and lessons learned applicable to the organizations involved and to ORNL in general (See Appendix A). Although not a Type B investigation, the review was conducted in the spirit of a Type B investigation as per DOE G225.1A-1, “Implementation Guide for Use with DOE ORDER 225.1A, Accident Investigations.”

2.0 FACTS AND ANALYSIS

Individuals Contacted

- Building 2026 Operations Manager, CSD
- Engineering Leader, NNFD
- Radiological Control Officer, NNFD
- Engineer, NNFD
- Former Building 2026 Facility Manager, NNFD
- Building 2026 Facility Supervisor, NNFD
- Radiological Engineer, NNFD
- RCT Group Leader for NNFD
- RCT Supervisor, OSSD
- Building 2026 RCT (2), OSSD
- Chemical Engineer (2), (NSTD)
- Laboratory Shift Supervisor (LSS) (2)
- Building 2026 Laboratory Technicians (2), CSD
- Building 2026 Facility Manager, NNFD
- Laboratory Waste Services Generator Interface, NSTD/NNFD
- BVLLLW Project Manager, BJC

Documents Reviewed

- Drawing 1386-H-107, High Radiation Level Analytical Laboratory Cell Details, Revision10/9/61 (new drawing 5-20169-Y-016-E-3)
- Drawing P3E-20169-C021, High Radiation Level Analytical Laboratory Fluid System Diagram Low Level Waste Drains, Revision 2
- Drawing P3E-20169-CO22, High Radiation Level Analytical Laboratory Piping System LLW 1st Floor Plan, Revision 2
- Drawing P3E-20169-CO23, High Radiation Level Analytical Laboratory Piping System LLW Enlarged Plans & Sections, Revision 2
- Drawing P3E-20169-CO24, High Radiation Level Analytical Laboratory Piping System LLW Details, Revision 2
- Drawing C3E-20013-A061, External Piping for HRLAL Service Lines Plan and Profiles, Revision 1
- Transcript of October 7, 2003, Event Critique, Radioactive Liquid Waste Spill at Building 2026 on October 6, 2003
- Emergency Action Level (EAL) Matrix for Building 2026, Rev. 7, August 2002
- Events Log from LSS entry for 1950, October 6, 2003
- Request for Authorization to Ship Nuclear Materials (NM) to Bechtel Jacobs Company LLC (BJCF-557), October 3, 2003
- Termination of Safeguards and Disposal of Material from the Building 3027 Vault De-inventorying Activity, June 25, 2003
- ORNL Wastewater Disposal Variance Request Form, June 24, 2003
- RMAL Work Instruction for Disposal of Nuclear Material from Building 3027 Vault, July 11, 2003
- E-mail from R. D. Canaan to M. E. Borum, Disposal of NMC&A Item, October 6, 2003

- White paper, “Termination of Safeguards and Disposal of Material from the Building 3027 Vault De-inventory Activity”
- NNFD Plan of the Day (POD) for Building 2026 for October 6, 2003
- Various other PODs
- Building 2026 Facility Supervisor’s Franklin Planner pages for September 4, 2003 and October 6, 2003
- CASD-OP-RML-FM03, Emergency Operating Procedure for the Radioactive Materials Analytical Laboratory (RMAL), Building 2026
- Spill Response, Discovery of Shock Sensitive Materials, and Reporting Requirements subject area
- Hot cell logs for cells 1, 2, and 3
- Identifying Significant Environmental Aspects and Impacts subject area
- Emergency Operating Procedure for the Radioactive Materials Analytical Laboratory (RMAL), Building 2026, CASD-OP-RML-FM03, Rev. 1
- RSS SOP, Incident Response, 02-346-02, rev. 5
- RSS SOP, Radiological Respiratory Protection, 02-530-01, rev. 3
- Radiological Worker Training Study Guide 2.08, Radiological Emergencies
- RCT On-The-Job Training Qualification Card
- RCT Continuing Training/Requalification Program
- Radiological Work Permit 2026-11546
- Radiological Work Permit 2026-12434
- Transcript of telephone calls to and from the LSS office regarding this event
- Final Report of the Contractor’s Operational Readiness Review of the ORNL BVLLL Waste Collection and Transfer System Upgrade: Building 2026 and Building 2099
- Phase 1A – Building 2026 Functional Test, X1989-01-0470

<u>Evolutions Observed</u>

- Radiological control technician rounds
- Entry into Building 2026 hot cell 3
- Building 2026 plan-of-the day meetings

2.1 ACCIDENT DESCRIPTION AND EVENT CHRONOLOGY

2.1.1 Accident Description

On October 6, 2003, in hot cell 1 of Building 2026, Chemical Sciences Division (CSD) personnel were conducting waste operations using manipulators to remotely denature, dilute, and dispose of liquid low-level waste (LLLW) into the Bethel Valley LLLW system. The waste contained plutonium and americium isotopes.

The denatured liquid was poured into a drain line fixed to an upper cell pan (visible from the hot cell window). The line, which passed through a lower pan (not visible from the hot cell window) and then into a waste storage tank located outside of Building 2026 (See Figure 1-1). This denatured liquid was flushed with about 5-gallons of process water. After this flush, process water in the hot cell was run for about 30 minutes at a flow rate of about 1 gallon/minute. The drain was partially plugged. As a result, the liquid filled one or more of the lower cell pans and then flowed under the cell door into the cell access area (Room 120).

Building 2026 personnel believed they sent about 40 gallons of liquid waste to tank 1401. The tank 1401 level history from WOCC for the time of the event indicated that tank 1401 had received about 100 gallons of liquid. The investigation team was unable to find adequate documentation to resolve this conflict.

The spill in Room 120 was discovered after normal operating hours by the facility radiological control technician (RCT) during normal facility rounds. The cell access area is a designated contamination area. The facility supervisor and the RCT were attempting to contain the spill when the Continuous Alpha Air Monitor (CAAM) alarmed. Immediately after the CAAM alarmed, the RCT and the facility supervisor stopped work and exited the area. The RCT and the facility supervisor monitored themselves using the personnel contamination monitor (PCM-1B) and no contamination was found on these personnel. Nasal swabs were collected from the RCT and the facility supervisor, and these indicated a potential uptake had occurred.

2.1.2 Event Chronology

A detailed time line of the event and recovery is contained in Appendix B. The following is a listing of the more important actions:

Prior to October 6, 2003

As part of an initiative to consolidate ORNL nuclear facility operations, Laboratory management desired to cease operation of the Building 3027 vault. As part of the project to deinventory the vault, ORNL desired to terminate safeguards on five items of "plutonium-241" and dispose of them as waste. Prior to the event on October 6, all five items had been dissolved. Four of these items had been denatured (^{232}Th added), diluted, and disposed of as low-level liquid waste from the Building 2026 hot cells. During these and previous evolutions, the technicians and facility supervisor, and operations manager noted the hot cell drains were "slow."

October 6, 2003

Approximately 12:15 pm: Five gallons of the denatured and diluted waste from the fifth l item was poured down the drain in hot cell 1. This was followed with about 5 gallons of process water that was poured down the drain from a container.

Approximately 12:30 pm: The drain was flushed with process water from an in-cell connection at a rate believed to be about 1 gallon/minute for about 30 minutes. The technician performing the work noticed that the drain was "slow," based on the tank 1401 level indicator in Building 2026.

Approximately 4:00 pm: The building RCT made a routine entry into Room 120 (behind the hot cells) and discovered water on the floor. The RCT exited the area and notified the facility supervisor.

Approximately 4:05 pm: The RCT and the facility supervisor returned to Room 120. The RCT measured about 20-30K dpm beta-gamma from the water. The RCT and the facility supervisor exited Room 120.

Approximately 4:15 pm: The RCT and the facility supervisor discussed options and re-entered Room 120 to attempt cleanup. They wore no respirators and attempted cleanup using mops, which were not effective.

Approximately 4:30 pm: The facility supervisor obtained a shop vacuum cleaner without a HEPA filter and they began vacuuming up the water. The vacuum was emptied into a Room 120 LLLW drain.

Approximately 4:50 pm: The caution alarm on the Room 120 continuous alpha air monitor (CAAM) activated. As the RCT and the facility supervisor exited Room 120, the high level alarm on the Room 120 CAAM activated. The RCT took a quick smear and advanced the CAAM tape. The RCT and the facility supervisor exited Room 120.

Approximately 4:55 pm: The RCT and the facility supervisor monitored themselves using the PCM-1B and for alpha contamination and found none.

Approximately 5:00 pm: The RCT called his supervisor. The supervisor suggested nasal smears. Nasal smears were taken, and readings were found to be above background.

Approximately 5:30 pm: The RCT informed his supervisor, who suggested the RCT call the shift HP office and the internal dosimetrist to arrange lung counts for the RCT and the facility supervisor.

Approximately 6:09 pm: The facility manager and the operations manager were notified.

Approximately 6:40 pm: The facility manager arrived at Building 2026.

Approximately 6:48 pm: The RCT and the facility supervisor went to Building 2008 for a lung count.

Approximately 6:48 pm: The building was checked for potential sources of water leaks, and none were found.

Approximately 7:20 pm: The event was classified, logged and the emergency action levels were reviewed.

Approximately 7:45 pm: The NNFD division director was notified, and the LSS sent a notification page.

Approximately 8:00 pm: The DOE facility representative was notified.

Approximately 9:04 pm: The RCT issued Radiological Event Report #1049.

Approximately 9:35 pm: Room 120 was re-entered by the facility technicians under a job specific RWP. The shift RCT retrieved air samples, inspects charts, and took smears. There was no evidence of airborne activity. The smears read 2.4E+6 dpm alpha. Cleanup was begun again.

Approximately 10:30 pm: The RCT and facility supervisor returned from their lung counts and were debriefed.

October 7, 2003

Approximately 12:15 am: Clearage of the water on the floor by facility technicians.

Approximately 12:30 am: The RCT and facility manager conducted a post-job brief.

Approximately 12:45 am: Involved personnel left ORNL.

2.1.3 Immediate Spill Response

The initial response to the event was by the RCT and the facility supervisor. After discovering the spill in Room 120 during normal rounds, the RCT contacted the facility supervisor. The RCT and the facility supervisor re-entered Room 120 and used a beta-gamma meter to probe the water that was spilled. The reading on the meter was 20-30K dpm, which was thought to be within the normal background range in Room 120. No alpha readings were taken, as the medium of interest was water (alpha detection is inhibited by water). The RCT and the facility supervisor attempted to clean up the water using mops. The mops were not absorbent enough and were not effective. At that point, the facility supervisor obtained a wet/dry vacuum cleaner that was not equipped with a HEPA filter and he and the RCT used it to clean up some of the spill. While in the process of using the vacuum, the caution alarm on the CAAM sounded. As the RCT and the facility supervisor were leaving the area, the high level alarm sounded. All of the preceding work was performed under an existing Radiological Work Permit (RWP) 2026-11546. The scope of work for this RWP was:

Routine lab activities, program/general maintenance activities and sample analysis activities. Contact Radiation Protection and building supervision before any work activities such as grinding, burning, sweeping, vacuuming and generation of fumes from caustic/acid reactions that would produce airborne radioactivity. Contact Radiation Protection and building supervision before breaking any surface paint bonds or work on any equipment internals (e.g., conduit, breaker boxes, light fixtures, piping etc.). Tools, equipment and other items being removed from contamination areas shall be surveyed, contained and tagged as appropriate.

Given the suspicion of airborne contamination after the CAAM alarmed, nasal smears were taken from personnel involved. The nasal smears were positive. The two individuals who were in the area when the CAAM alarmed were sent for a lung count to detect internal contamination and urinalysis for these individuals was initiated.

This RWP was deemed appropriate because the RCT and the facility supervisor did not consider having water behind the hot cells as a “non-routine” event. Various people interviewed said that water was sometimes found on the floor behind the hot cells. Estimates of frequency for this varied from about once every two or three years to once every three months. Typically, the water was from rain or from equipment in the room above Room 120. As a result, that water was clean water and was cleaned up using the standing RWP. The PPE used for the initial cleanup efforts was Tyvek coveralls, shoe covers and double rubber gloves, and safety glasses. No respiratory protection was required. At the critique the day after the event, the RCT said they suspected the water came from the hot cell. Later, he said he had thought it was clean water, (meaning the levels he saw were not out of the norm, no that the water had no radioactivity). The facility supervisor said they had considered the water to have come from hot cell 1. The operations manager said that any water on the floor in Room 120 should be considered as alpha contaminated, as the hot cells are used to handle items with high alpha levels.

Subsequent to the CAAM alarms, all entries made into Room 120 that evening were conducted under the control of RWP 2026-12434. The RWP upgraded the PPE requirements to include splash proof coveralls and respiratory protection. The RWP was terminated on October 7. The scope of work for that RWP was:

RCT to enter cell access area to retrieve air samples, reset CAAMs, and start new air samples. Facility personnel will then enter area to collect water behind cells 1, 2, and 3. After water has been collected *into enclosed container, personnel will proceed with first decon attempt.*

Those involved in the cleanup said they followed the existing procedures during the cleanup. The ORNL procedures, Radiological Worker training program, Radiological Control Technician training program, Radiological Support Services procedures, and Building 2026 Emergency Operating procedures regarding spill response activities were reviewed. Most of the procedures referred to releases to the environment, with little emphasis on spills inside buildings or other containment.

The Standards-Based Management System (SBMS) holds the parent command media for the Laboratory. The subject areas in SBMS establish the minimum requirements for ORNL staff. Those significant to spill response and/or identification of abnormal events include the following:

- The Spill Response, Discovery of Shock Sensitive Materials, and Reporting Requirements subject area requires the following:
  - The person observing the spill calls the LSS "when assistance is required".
  - The Initial Spill Response procedure within this subject area states that "all releases of hazardous materials or regulated pollutants to the environment must be reported to the LSS office." It is silent with respect to radiological spills or personnel exposures.
  - Step 1 of this procedure refers the reader to the Handling Abnormal or Emergency Conditions Procedure of the Performing Radiological Work subject area for radioactive material spills or releases.

- Procedure: Handling Abnormal or Emergency Conditions, Performing Radiological Work subject area
  - This procedure lists the alarm of a continuous air monitor as an emergency.
  - This procedure lists the spill of radioactive materials as an abnormal situation. Note: the procedure does not specifically mention the discovery of spills in contamination areas, but a revision to this effect is now under Laboratory-wide review.
  - Action steps include minimizing the individual exposure and contamination.
  - This procedure also notes that cleaning up any radioactive material spill requires an appropriate RWP and RCT coverage.

- Subject area: Occurrence and Non-routine event Response and Reporting
  - This subject area establishes ORNL procedures and methods for event response and reporting. The introduction to the subject area states: "ORNL management expects employees to report all abnormal events, even those deemed to be small, seemingly insignificant or low-level events or conditions."
  - Step 1 of the first procedure in this subject area requires staff to "report any actual or potential abnormal event or condition to supervisors or the LSS."
  - The procedure directs personnel to initiate immediate actions to mitigate or control the event after notification of supervision or the LSS.

2.1.4 Long-Term Recovery Plan

Following the event, Building 2026 and support personnel began developing a Recovery Plan to get into the hot cells, determine what had occurred, and develop plans to resolve any issues that were identified. The working/planning meeting for the Building 2026 Recovery Plan, Investigation and Troubleshooting was attended on October 30, 2003. The following were noted:

- Attendees included the acting facility manager, facility supervisor, two technicians, two RCTs, an

NNFD Engineer, the NNFD DRCO, the NNFD/OSSD radiological engineer, and the NNFD/OSSD industrial hygienist. The operations manager observed the second half but did not participate.

- The review was preceded by the NNFD engineer's explanation of the "Bldg 2026 LLLW System Recovery Test Plan," 2026-03-01A, which he had recently drafted and had working through the sign-off chain.
- The next major recovery action would be controlled with Work Package "2026-CELLDRAINS-01/0" and entailed flow testing of the LLLW drain line from the Room 120 floor drain and then moving to inspection and testing of the drain pan in the bottom of hot cell 3.
- The facility supervisor walked through each step of the draft work package collecting and facilitating the resolution of comments from all attendees. Many minor adjustments were made to improve accuracy, efficiency, ALARA, etc.
- The draft RWP was reviewed by the RCT, including plans for electronic dosimeters, a 50 mrem total dose alarm, a 500 mrem/hr dose rate alarm with 250 mrem/hr reset, and layering of PPE. Technician questions about dose limits and estimated work conditions and times were discussed.

The pre-job brief prior to the initial cell entry was observed and the following were noted:

- The pre-job brief was attended by all directly involved and support personnel. No supplemental briefings of others were required.
- The facility supervisor quickly walked through the approved work package emphasizing changes from the last version reviewed over two hours the prior Thursday (October 23, 2003). Last minute clarifications, coordination, and confirmations were made.
- The NNFD Work Package format contains three columns: one for the action, one for the hazard/control and one to identify the action performer. In this case the center column was only populated in the Prerequisites section. Each action step did not identify the corresponding hazards and controls.
- Review of the RWP was missed during the pre-job brief but was conducted during dressout. The RWP called for three layers of coveralls. (Tyvek/Saranex/Tyvek), use of electronic dosimeters, a 50 mrem total dose alarm, a 500 mrem/hr dose rate alarm with 250 mrem/hr reset. None of these limits were exceeded during conduct of the work.
- Entry was made by two technicians, one RCT and one Building 2026 Investigation Team observer.

The initial entry into the cell access area (CAA) and cell three and the post-job brief were observed, and the following were noted:

- The CAA was cluttered with over 30 large bags of radiological waste from recovery efforts.
- Smoke testing and 20 gallon flush test of the floor drain revealed adequate flow.
- Cell 3 was the only hot cell door whose opening mechanism was chained and locked. The team did not have the proper key to open the door. The chain was secured to latching dogs on the door face, which was missing a pivot bolt allowing the chain to be slid off and allowing operation of the opening mechanism. The chain was later cut off to ease opening mechanism handwheel operation.
- Preparation of the cell 3 door by attachment of herculite drapes was slow and required considerable technician exertion (holding drapes, laying duct tape, etc.).
- The door opening mechanism was out of adjustment and would not initially move the door. The drive chain from the handwheel-driven gearbox to the drive axle was loose and slipped on the axle gear. The door was successfully moved when one technician used his hand to tension the chain while the other turned the handwheel. A hand-pinching hazard, while theoretically possible, was not a practical concern due to the slow speed and low pinch point.

- Radiation readings at the door jam, with the door approximately six feet back, were approximately 500 mrem/hr open window and 20 mrem/hr closed window. Dose or dose rate limits were not exceeded during the course of the entry, as recorded by the electronic dosimeters.

- Numerous photos were taken of the lower cell area which revealed the following:
    1. The physical configuration was consistent with the drawings.
    2. There were miscellaneous materials in the bottom pan of cell 3, including a plastic bag, two aluminum manipulator boot rings and approximately 30 lead bricks.
    3. The bottom pan of cell 3 was dry but had clear evidence of having been entirely filled with standing water in the past (waterline stains clear on the lead bricks). Stains under the hot cell door indicated spills under the hot cell door had occurred.
    4. Flow testing with water showed the drain backed up into the bottom pan at approximately 14 gallons. A total of 16 gallons was poured down the drain. The water level in the bottom pan of cell 3 did not appear to drop for over 45 minutes after the water additions stopped.
- During the last hour of the entry, the two technicians showed signs of exhaustion and minor heat stress. Frequent breaks were taken to compensate for the stress, but the workers were noticeably less stable (i.e., being able to balance on one foot unassisted) upon exit than initially.

2.1.5 Medical Summary

The results of the nasal smears, lung counts, and urinalysis for the RCT and the facility supervisor involved in the immediate spill response indicate that an uptake did occur. As of the date of this report, only the preliminary estimate of the committed dose equivalent is available. In both individual cases, the Total Effective Dose Equivalent (TEDE) and the Committed Dose Equivalent (CDE) are below the 10 CFR 835 dose limits of 5 rem TEDE and 50 rem CDE and are below the DOE and ORNL Administrative Control Limits of 2.0 and 1.5 rem, respectively.

2.2 HAZARDS, CONTROLS, AND RELATED FACTORS

2.2.1 Physical Controls

The physical construction of the hot cells did not allow one to visually determine if liquid poured down the hot cell drain was backing up into the hot cell's lower pan. In addition, the level instrumentation in Building 2026 associated with the drain tank (tank 1401) did not provide timely or effective indication that the liquid poured down the drain was being received (See Figure 1-1).

The drains in the hot cells were 1-in pipes that extend from the upper pan down through a slotted 2-in pipe in the lower pan and into the BVLLLW system piping. The drains in the upper pan did not have anything in place to preclude foreign material from getting into the drain system and plugging it. As far back as 2000, and on numerous occasions prior to this October 6 event, “slow” draining of liquid from the hot cell drains had been noted, but not officially documented. As such, the repair of the drains was not in a maintenance backlog and was not scheduled.

Also on numerous occasions, the correlation between the amount of liquid sent to tank 1401 and the amount indicated as received was not in accord. There were two different kinds of level indicators associated with tank 1401. While both of these are used by Duratek personnel in the WOCC to monitor level, Building 2026 has indication from only one of the two. The WOCC and Building 2026 indicators were not calibrated at the same time and there was no program or effort to ensure that they agree with each other.

There was a process drain in Room 121, adjacent to Room 120. Some of the water from this event went into this drain. WOCC personnel are now aware of this, and have taken the actions they deem appropriate.

2.2.2 Management Systems

The management systems associated with the immediate response are addressed in Section 2.1.3, Immediate Spill Response, above. In addition to those management systems, there were many others that were challenged during this event and the recovery from it.

2.2.2.1 Material accountability

Early in the recovery from the event, a question arose as to whether there was a material accountability issue due to the fact that not all of the waste material had actually reached tank 1401. A subgroup of the investigation team was formed to address this issue.

2.2.2.2 Communications

The RCT on duty the day of the event said he was not aware that the activities in hot cell 1 involved material containing high alpha. He also said he had attended the POD meeting. One of the technicians involved in the event said he also attended the POD, and material to be processed and the procedures were discussed. Based upon the POD meetings observed and discussion with the operations manager, who runs the POD, apparently the POD meetings do not get into detail on the specific activities to occur during the day. In fact, the operations manager said that sometimes activities, such as the cell 1 activities on the day of the event, may not appear on the POD because they have not been approved at the time of the POD. However, they are performed once all the necessary approvals are obtained. Attendance at POD meetings is not taken.

At one point, the individuals responding to the event in Building 2026 called the LSS to get a telephone number for the Hazmat contact and were given the wrong phone number. Subsequently, it was determined that there were three different lists in the LSS office that contained telephone numbers for the Hazmat contact, and one cell phone number was incorrect.

During the immediate response to the event, the RCT program leader called the spill response team to determine what equipment they had available. She did not ask for help at that time. Later, various individuals said the spill response team does not respond to radiological spills within nuclear facilities.

When the LSS was notified of the event, which occurred at shift change, the offgoing and oncoming LSSs went to Building 2026. They assessed the situation against the emergency action level (EAL) guidance and decided that it did not meet any of the criteria. However, the EALs did not define an operational emergency for Building 2026 as they do for some other facilities. (The Building 2026 EMHA, which develops and defines the EALS has just recently been updated and is in the approval process.)

2.2.2.3 Work control

The Work Control subject area required all work to be “evaluated through the appropriate procedure prior to start of work activities.” Evaluations for projects or activities were documented through work packages for maintenance and operations activities and or research safety summaries for research and development activities.

Completion of the appropriate evaluation path constituted line management authorization for work to proceed, within the limits imposed by that work package or RSS. The team reviewed work control documents related to this event.

The research activities leading up to this event were authorized under a research safety summary (RSS) 567.1 titled, "General Operations in the Radioactive Materials Analytical Laboratory (RMAL), Building 2026." The following observations were made with regard to the RSS:

- This RSS covered research, development, validation and application of analytical methodology.
- The RSS invoked the requirements of all CSD and NNFD standard operating procedures and standard analytical methods applicable to Building 2026 operations. It also referenced the SAR and TSR as bounding documents.
- The RSS required that "all modifications to operations that could potentially affect building operations or that constitute a previously unidentified hazard or a hazard that can not be mitigated with existing controls must be reported to the facility manager for USQ screening." The facility manager did review the RSS and the work instruction for this project. A USQ screening was not performed.
- The CSD SOPs allowed for the development of work instructions to customize analytical methods to a given sample or matrix. In this case, a work instruction was written for the dissolution and denaturing of the material. It further referenced the analytical methods to be used to prove the appropriate plutonium to thorium ratio.
- The RSS required that all new waste water streams be approved by the division EPO prior to discharge. The variance for this stream was handled by an NSTD generator interface and signed by a CSD generator for discharge in an NNFD facility. It was not reviewed by CSD operations personnel.
- This RSS did not specifically address decontamination.
- The RSS identified the generation of LLLW and invoked the requirements of the Managing Wastewaters subject area. That subject area defined the requirements for denaturing.

The R&D work control procedure require the principal investigator to initiate a new or additional ESH review when changes occurred that could affect the safety envelope of the project, as defined by the RSS. The PI decided that the denaturing work fit within his approved scope of work. An additional ESH or RSS review was not conducted.

2.2.2.4 Waste management

There is remote-handled material stored in the lower cell pans in most of the cells. The material consists of everything from lead bricks to plastic bags of material. There is no inventory of what material is stored in this manner.

3.0 ANALYSIS

3.1 IMMEDIATE SPILL RESPONSE

During the review of the guidance documents associated with spill response, the following were noted:

- There is very little information or specific guidance provided in the procedures regarding spills within the design features of laboratory buildings (e.g., from primary to secondary containments).
- The definition of a "small spill" varies from less than one gallon (Spill Response, Discovery of Shock Sensitive Materials) to a few ml (Radiological Worker Training, Study Guide 2.08, Radiological Emergencies). "Large spills" are not specifically defined.
- The Initial Spill Response procedure directs the observer to contact the LSS regardless of the size of the spill.
- The Small Spills procedure directs the observer to notify the "responsible division management" for spills less than one gallon and "not impacting soil or surface waters."
- The Cleanup of Spills procedure does not distinguish inside verses outside area spills. However, Section 2.0, step 5 refers the reader to the Identifying Significant Environmental Aspects and Impacts subject area. Again, there isn't much direction for inside spills.
- The procedures addressing PCB spill recovery contained the best level of detail of all the procedures reviewed. They identified decision thresholds, specific types of personnel along with responsibilities. This could serve as a model for upgrading procedures for radiological spills.
- Radiological Worker Training 2.08 identifies small spills as a few ml, which conflicts with the less than one gallon definition in Spill Response, Discovery of Shock Sensitive Materials.

The procedures provide very little detail identifying who has responsibilities for specific actions. The procedures are difficult to follow with too many steps directing the reader to go to another procedure for further guidance to complete a single task. The Building 2026 Emergency Operating Procedure does not address spill response. The procedures do not establish some of the fundamental requirements associated with liquid spills in contamination areas. For example, one would expect one of the first actions after finding water in a contamination area to determining the level of contamination of the water. If it is reasonable to expect alpha, as it was in this case, then a methodology for determining the level of alpha contamination should be established, which would include donning a respirator.

3.2 PHYSICAL CONTROLS

The physical construction of the hot cells required that technicians pour liquid waste into a drain without being able to see if that drain backed up due to a clog in the drain. As evidenced by this event, this design can result in problems. In addition, the tank level instrumentation was not sufficiently responsive to allow Building 2026 personnel to ensure that there was proper flow when dumping waste down the drain. If there is no way to allow the technicians to visually ascertain the status of the drains when waste is being poured into them, it is even more important that the tank level instrumentation be responsive. Typically, there is a mechanism to allow the individuals involved to ascertain that liquid is leaving one place and arriving at the other. In this case, the tank 1401 level indicators could be used to verify that liquid is indeed being transferred and to quantify the amount being transferred, which would help identify problems similar to those associated with this event prior to having a large spill. Unfortunately, the large volume of the tank (about 1800 gal) and the small volumes released by Building 2026 (usually < 10 gal) make reliable measurement of volumes difficult.

The drains in the hot cells were not equipped to preclude entry of foreign material that might cause a clog in the drain. There is anecdotal evidence of everything from bottles to bottle caps to “iridium bones” (undissolved aluminum from iridium targets) having been placed into the drains. There is also evidence that the drains had been “slow” for quite some time, and that personnel had learned to live with this, rather than having the drains tested and unplugged. It is imperative that problems such as plugged drains be identified as quickly as possible, so they may be documented and put into the maintenance system for correction. Learning to live with equipment that is less than adequate is one of the first steps leading up to an undesirable and unnecessary event of some kind.

During this event, some of the spilled material entered the process drain in the floor in Room 121. The process drain system is not designed to handle radioactive water. Having an open floor drain to the process system in a contamination area is an invitation to contaminate the process system.

3.3 MANAGEMENT SYSTEMS

3.3.1 Immediate Spill Response

It is not clear why the spill response team does not routinely respond to radiological spills as well as other spills. Much of the equipment and material needed for spill response is applicable to all types of spills. The current thinking is that facility personnel are capable of handling radiological spills including decontamination. However, as was the case in this event, personnel resources were severely stretched during initial and recovery activities. Had the decontamination continued for much longer, there would not have been sufficient facility personnel to respond to the event. ORNL needs more depth in personnel trained in specialized decontamination activities. In addition, the roles of the LSS in events similar to this need clarification.

3.3.2 Material Accountability

The Material Accountability Subgroup determined that material accountability had been maintained. This report is contained in Appendix C. The investigation agrees with the conclusions of the Subgroup.

3.3.3 Communications

The POD meetings are not effective in communicating and documenting the day’s activities to all involved parties. For example, the RCT involved in the event said he was not aware of the specific activities on the day of the event, even though he had attended the POD meeting. All involved parties, such as NSTD personnel do not always attend the POD meetings.

The roles and responsibilities in Building 2026 are not well defined and sometimes conflict. For example, CSD expects the operations manager to conduct POD meetings. NNFD expects the facility manager to conduct POD meetings.

3.3.4 Work Control

The RSS under which this activity was performed addressed research, development, validation, and application of analytical methodology. This activity was dissolution and denaturing of material for disposal. The only analytical work conducted was to prove that the correct ratio had been achieved for denaturing.

As a result of not recognizing that this work was actually beyond the scope of the existing RSS, some work control activities were not completed. For example, no USQ screening was performed. Also, with the exception of the Building 2026 operations manager, CSD management was not involved in things such as the variance to allow disposal in this manner.

3.3.5 Waste Management

The storage of material in the bottom of a hot cell is not prudent. It is even less prudent when the material cannot be seen without opening up the hot cell and the material is capable of being repeatedly wetted by aqueous discharges and plugging the hot cell drains under the right conditions.

3.4 LONG-TERM RECOVERY PLAN

NNFD Engineering subsequently prepared a detailed test recovery plan to address the drain recovery in particular. This test plan appropriately addresses:

- The iterative nature of investigation, testing/troubleshooting and response evaluation typical of this type of recovery.
- The major issues to be addressed including recovery of drain function, material accountability, hot cell condition assessment and engineering of long-term corrective measures.
- A risk and logic-based methodology which works backwards from the receiver tank to quantify the operability of each section of the drain system.
- Involvement and concurrence of the key facility (both R&D and NNFD) and safety personnel.

The 2026 recovery is following, and NNFD Engineering is adjusting, this test plan as each new major evolution is conducted and additional insights as to the condition of the 2026 drains are compiled. The review team concludes the 2026 test plan is technically sound and is being administered appropriately.

The plan laid out a clear strategy and logic for how the recovery would proceed and what goals were intended to be accomplished. The meetings held to discuss the plan and the individual portions to be conducted at a specific time were excellent demonstrations of team participation and synergy. All required parties were present and involved in the discussion of the proposed activities. As a result, improvements were made to the plan prior to getting into the area where work was to be performed.

The cell 3 entry was well controlled. Activities were conducted in accordance with the plan and, in general, went in accordance with the plan. The entry was made without incident and all workers displayed proficiency and diligence in their assigned tasks, contamination control and ALARA. The desired information was obtained. It was determined that the spill occurred because of a drain line blockage (or partial blockage) downstream of cell 3. This blockage resulted in liquid backing up into the lower pans in one or more of the cells and overflowing out the doors. The NNFD engineer estimates the 14-gallon volume (which is the amount poured down the drain when the backup into the lower pan in cell 3 occurred) closely correlates with a blockage downstream of the cell 3 tie-in to the drain header but upstream of the main “T” with the drain line exiting the building. It appears that cells 1, 2 and 3 are “communicating” between themselves via the drain header.

As the event investigation was nearing completion, an entry was made into cell 1. The condition of the lower part of the cell was significantly more cluttered with material than was cell 3. As part of this entry, acid was used to attempt to unplug the drain. At the time of this report, that effort appears to have been successful.

3.5 ANALYSIS TECHNIQUES

3.5.1 Integrated Safety Management System

Management systems were examined as potential contributing and root causes of the event. The investigation team reviewed the roles of those individuals who were directly or indirectly involved in the event. UT-Battelle has a formal, organized process for planning, performing, assessing, and improving the safe conduct of work. Properly implemented, ISMS is a "standards based approach to safety," requiring rigor and formality in the identification analysis, and control of hazards. The system establishes a hierarchy of components to facilitate the orderly development and implementation of safety management at ORNL. The guiding principles and core functions of ISM are the primary focus in conducting work efficiently and in a manner that ensures the protection of the worker, the public, and the environment.

ORNL's ISM program has been contractually required since 1998. UT-Battelle assumed those ISM requirements when it took over as the management and operations contractor for ORNL on April 1, 2000. UT-Battelle has an approved ISMS program. However, the investigation team identified weaknesses in application of several of the core functions. These weaknesses are addressed in the Judgments of Need contained in Section 4 of this report.

3.5.2 Barrier Analysis

Barrier analysis was performed for the Building 2026 event using Management Oversight and Risk Tree (MORT) analysis and is shown in Appendix D. The analysis looked at barriers on the energy source (water used in the process), between the energy source and targets (personnel and the process drain), on the targets, and the possibility to separate in time or space. Any credible barrier is a causal factor because if used it would prevent the event.

The analysis concluded that barriers on the water source were not needed under design conditions, namely that the 1-in drain line can flow the expected rate of water. Barriers between the hazard and targets were not provided, such as a water level alarm in the cell floor or a physical means of inspection, and barriers on the personnel (PPE) and the process drain (capping or other water intrusion prevention) were not used. Additionally, the degraded performance of the drain causes the hazard not to be separated in space from the target.

3.5.3 Change Analysis

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

3.5.4 Causal Factors Analysis

Causal factors were generated using Institute of Nuclear Power Operations (INPO) causal factors worksheets. Three problems were chosen for analysis 1) the obstruction of the drain by operational practices; 2) the failure to fix the drain and lack of consideration of the known slow drain flow given the larger water volumes planned for the deinventory work; and 3) the initial response that resulted in personnel exposure to airborne radioactivity. The identified causal factors were sorted using a logic tree approach and are shown in Appendix F.

The analysis concluded that the flooding of the cell access area resulted from inadequate information used to support the decision to process the waste in the manner proposed given the suspect condition of the drain, and a failure to fix the drain which resulted from a misunderstanding of the risks and consequence of continued operation with degraded equipment. The analysis also concluded that the response methods that resulted in personnel exposure primarily resulted from a lack of clear guidance on the recognition of, and response to, upset or abnormal conditions. This guidance would normally be expected to be contained in procedures or similar instructions, and training. Both the decision to operate under the actual conditions and the initial response to the event are the result of inadequate information to operate as was actually done.

3.5.5 Root Cause Analysis

Root cause analysis is used in accident investigations to identify those deficiencies, including management systems factors that, if corrected, would prevent recurrence of the accident. Numerous analytical methods are available. For this event, the investigation team utilized the analytical tree methodology described in DOE G 231.1-2, *Occurrence Reporting Causal Analysis Guide.* The following direct, contributing, and root causes (Appendix G reference codes in parentheses) were determined.

Direct Cause:
Equipment problem - contaminant in drain line that partially blocked the line causing liquid to back up in the line, into the lower cell pans, and overflow the lip of the lower cell pans onto the floor of Room 120. (A2B6C06)

Root Cause:
Management policy not enforced - management allowed a culture to exist where degraded equipment performance was known and accepted without investigation and correction. (A4B1C01, A4B1C05, A4B2C08)

Contributing Causes:
Design less than adequate (LTA) - There was no provision in the design to provide alarms or other information to technicians regarding the possibility of liquids that had overflowed or backed up into the lower cell pan.

- The design did not consider all the possible scenarios. All the operating conditions, (normal and emergency) were not included in the design. (A1B2C01)
- Errors not detectable. Personnel were unable to reliably detect errors (by way of alarms or instrument readings) during or after the occurrence. A serious error went unnoticed because there was no way to monitor the system status. (A1B2C08)
- Inadequate equipment controls or control systems contributed to the occurrence. Operating conditions (lack of alarms or instrumentation for liquids in lower cell pan, restricted vision, etc.) affected performance of the task. (A1B5C02)

Human Performance LTA - Technicians had become accustomed to utilizing the tank indicator as a qualitative indication that liquids had successfully passed into the tank 1401. Individuals underestimated the problem by using past events as basis. (A3B3C06)

Work Control LTA - The Research Safety Summary, Work Instructions, and Plan of the Day meeting and document were not adequate to define work and related potential hazards, and were not communicated to all workers involved in facility operations.

- Job performance standards not adequately defined. (A4B1C02)
- Job scoping did not identify special circumstances and/or conditions (A4B3C08)
- Work planning not coordinated with all departments. (A4B3C09)

Communications LTA - Communications between operations and support were less than adequate. Communication between work groups LTA. (A5B4C01)

4.0 JUDGMENTS OF NEED

Judgments of Need are the managerial controls and safety measures determined by the investigation team to be necessary to prevent and/or minimize the probability or severity of a recurrence. They flow from the causal factors, which are derived from the facts and analyses. Judgments of Need are directed as providing guidance for managers during the development of corrective actions. The following are determined to be the Judgments of Need specific to Building 2026 resulting from this event. It is assumed that the corrective actions developed in response to these Judgments of Need will address the issues Laboratory wide, as appropriate.

The Judgments of Need are placed in three basic groups as follows:

Physical Needs

1. The drains from the hot cells need to be unplugged and maintained clear.
2. Means need to be developed to minimize the amount of foreign material that can enter a hot cell drain.
3. There needs to be a reliable mechanism to allow the hot cell technicians to monitor the liquid level in the lower pans in the hot cells.
4. All open process drains in contamination areas needs to be identified and the acceptability of having them remain open needs to be evaluated.
5. The waste material stored in the hot cells lower pans needs to be removed and disposed of.
6. The function of the Building 2026 tank 1401 level instrumentation needs to be determined in order to ensure the configuration supports this function.

Administrative Needs

7. Spill response directives and guidance need to be consolidated and updated to accurately describe the process for identifying and responding to radiological spills.
8. The roles and responsibilities of the Laboratory Shift Superintendent, ORNL spill response team, radiological control technicians, and facility personnel need to be evaluated relative to radiological spills inside of buildings.

Managerial Expectations

9. Management needs to ensure that personnel understand that problems identified in nuclear facilities are required to be identified and documented. These items need to be prioritized with the involvement of all stakeholders based upon programmatic and safety risk.
10. Management needs to ensure that work control documents have adequate detail to address the specific scope of work, the associated hazards, and the controls.
11. Roles and responsibilities that are consistent amongst organizations working in Building 2026 need to be developed and promulgated.
12. Plan-of-the-Day (POD) meetings need to be modified to ensure that all required parties attend the meetings and that all work expected to be performed that day is documented and discussed in sufficient detail to understand and execute planned work and manage facility interfaces.
13. The practice of storing material in hot cells needs to be evaluated.
14. The control and use of vacuum cleaners (HEPA and non-HEPA) in nuclear facilities needs to be evaluated.

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APPENDIX A. REVIEW TEAM CHARTER

Review Team Charter

Building 2026 Radiological Event

(revised October 28, 2003)

Introduction

The Building 2026 Radiological Event Review Team will evaluate the October 6, 2003 radiological event in Building 2026, identify contributing and root causes, and develop appropriate recommendations and lessons learned applicable to the organizations involved and to ORNL in general.

Scope

The scope of the review includes all aspects of the Building 2026 event and implications for work performance, safe operations, and organizational interfaces.

Approach

The review team will utilize general guidance for Type B investigations as a guide in performing the review. The team will have access to all documents and staff involved in the event and related facilities.

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Jeff Long, Facilities and Operations
Mark Kohring, Operational Safety Services Division (nuclear safety)
Steve Hamley, Operational Safety Services Division (radiation protection)
Paul Gubanc, Nonreactor Nuclear Facilities Division
Kim Jeskie, Chemical Sciences Division
Dale Perkins, Operational Safety Services Division (radiation protection)
Richard Haire, Subject Matter Expert, Chemical Sciences Division
Robert Wham, Subject Matter Expert, Nuclear Science and Technology Division
Mike Henderson/Mark Robinson, DOE observers
Joe Herndon, Nuclear Science and Technology Division

Reporting and Deliverables

The team will provide the sponsoring Level One managers with frequent progress reports during the course of the review. The team will provide a summary presentation to Senior Management and a final report identifying contributing and root causes, lessons learned, and recommendations to prevent similar events from occurring and improve operational discipline across ORNL.

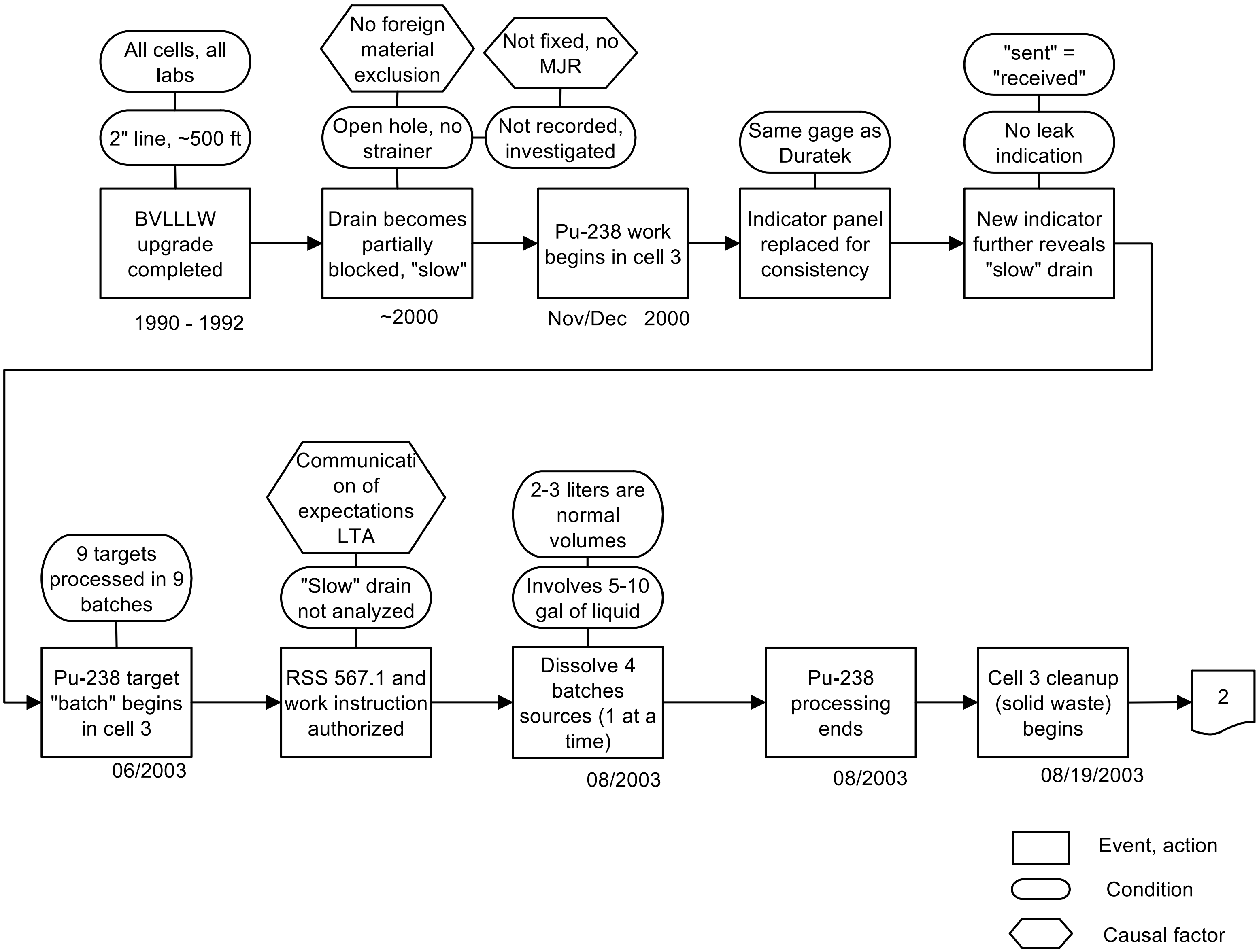
Approved:

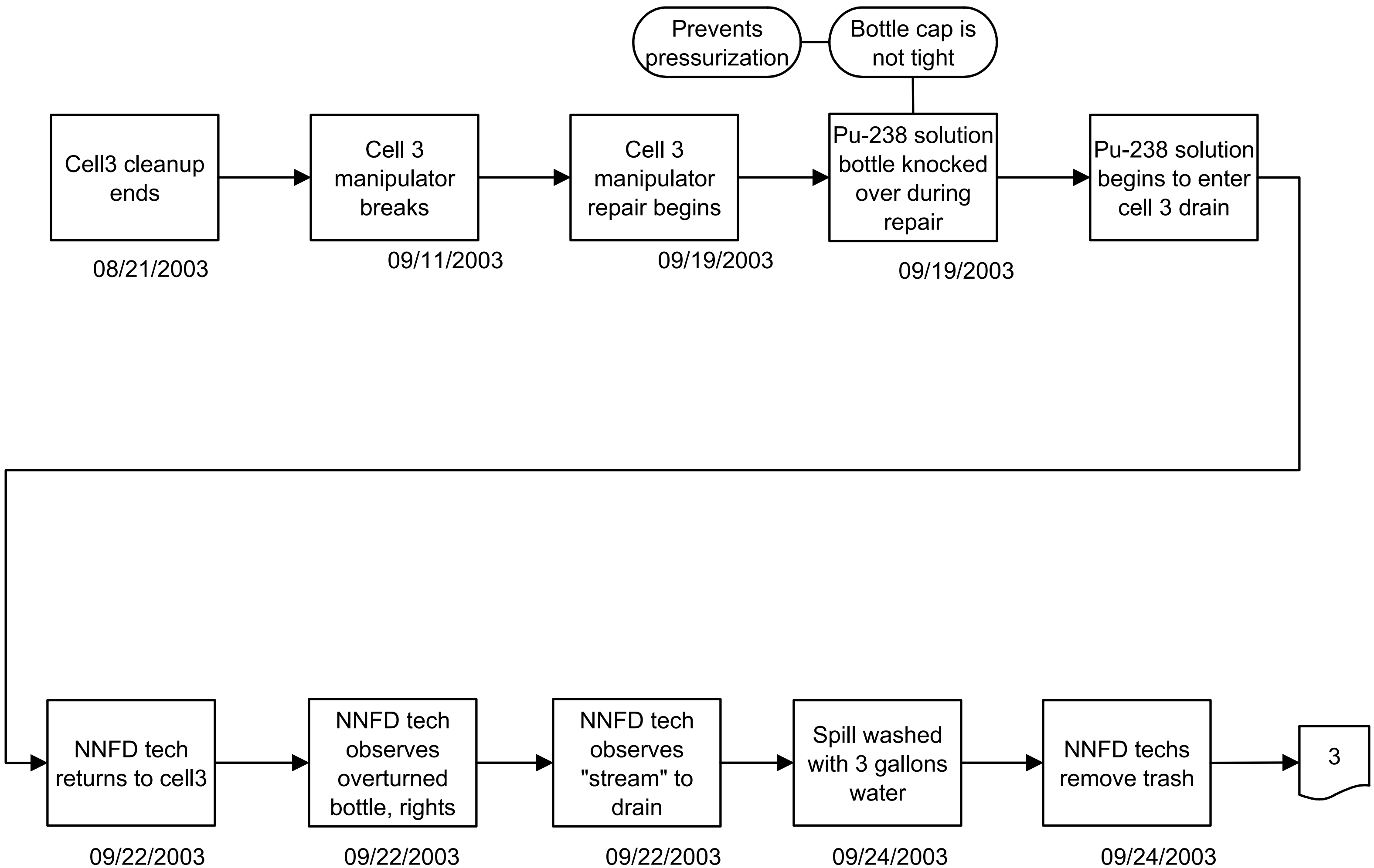
J. B. Roberto, Associate Laboratory Director

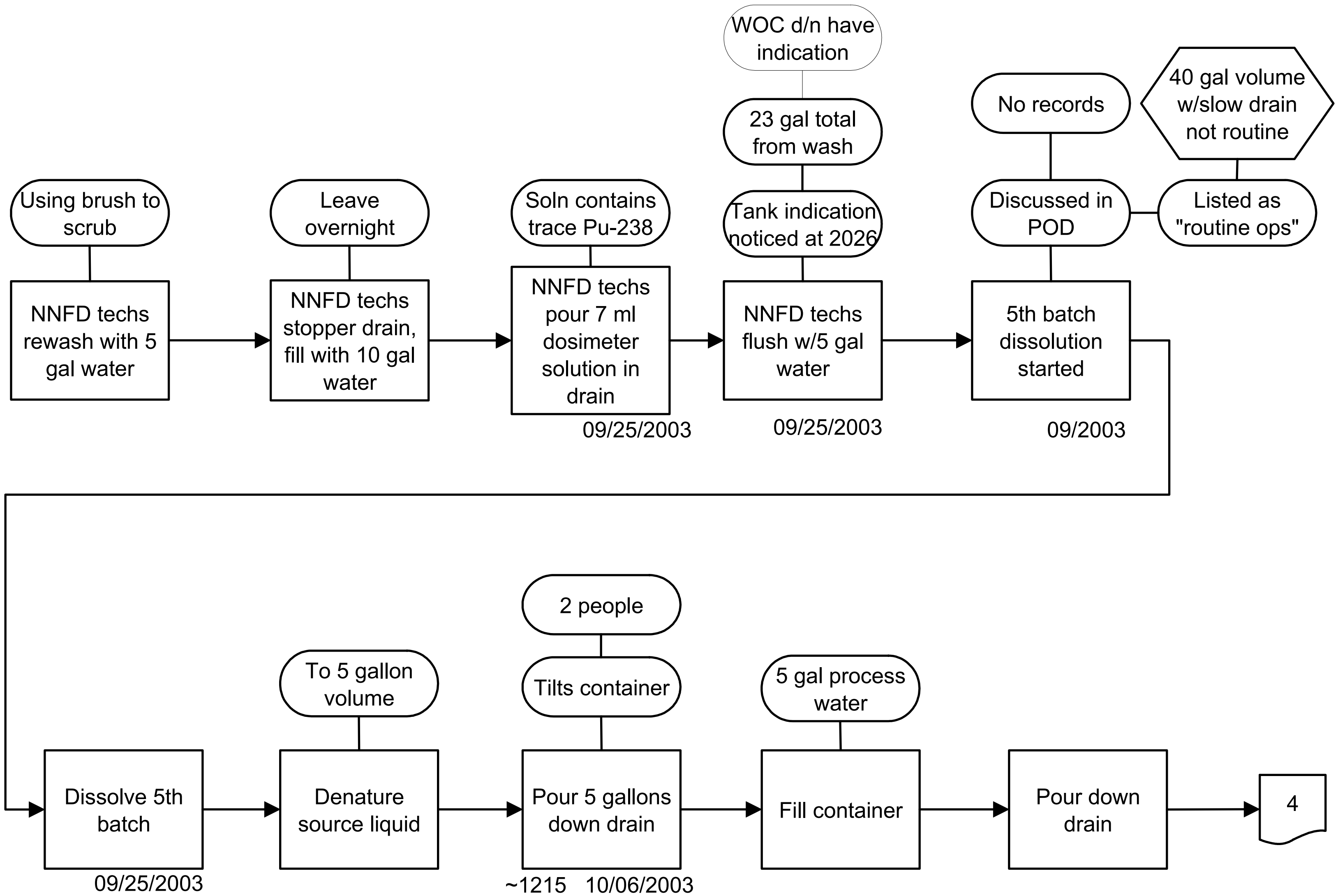
Kelly Beierschmitt, Director, ESH&Q

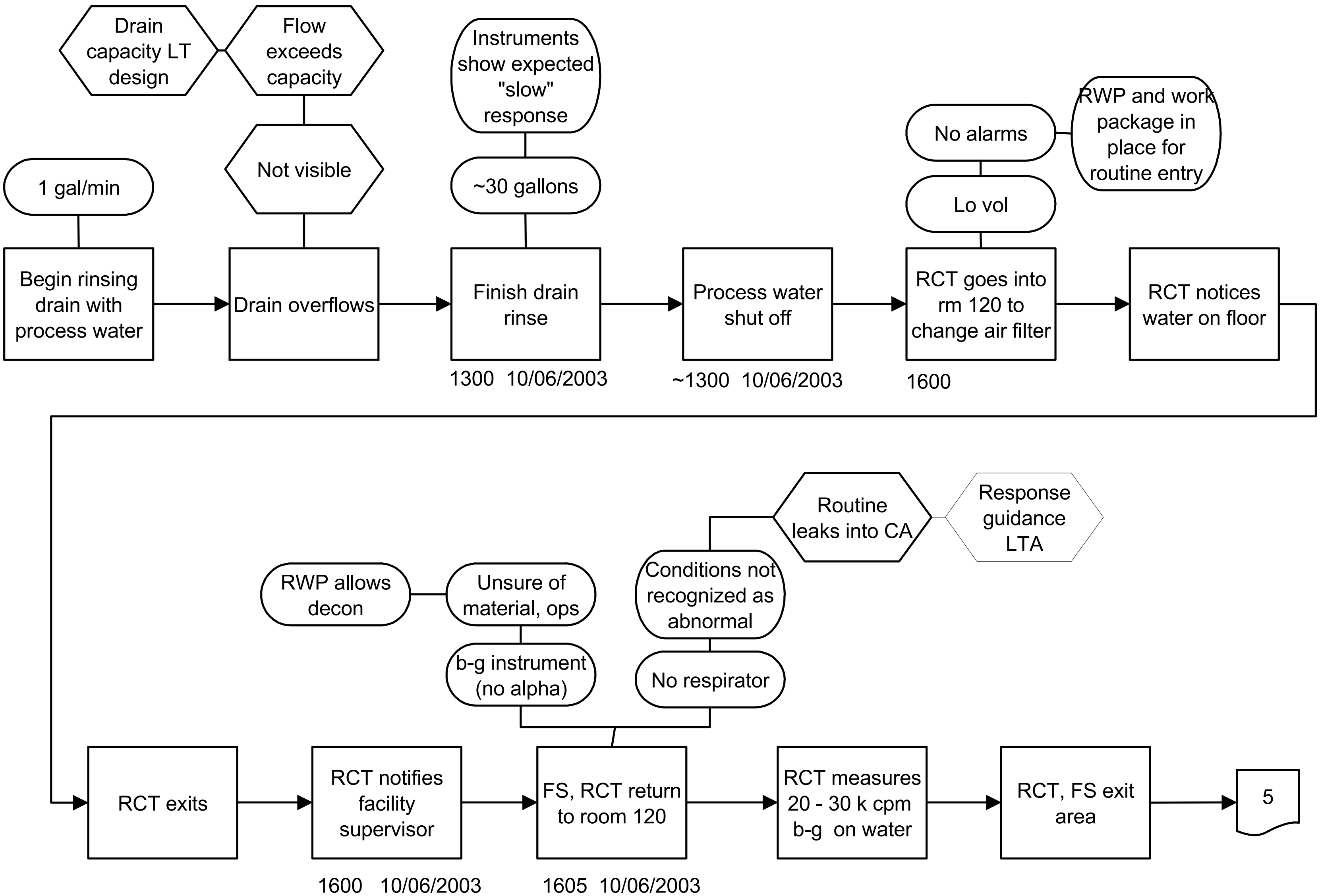
Herb Debban, Director, Facilities and Operations

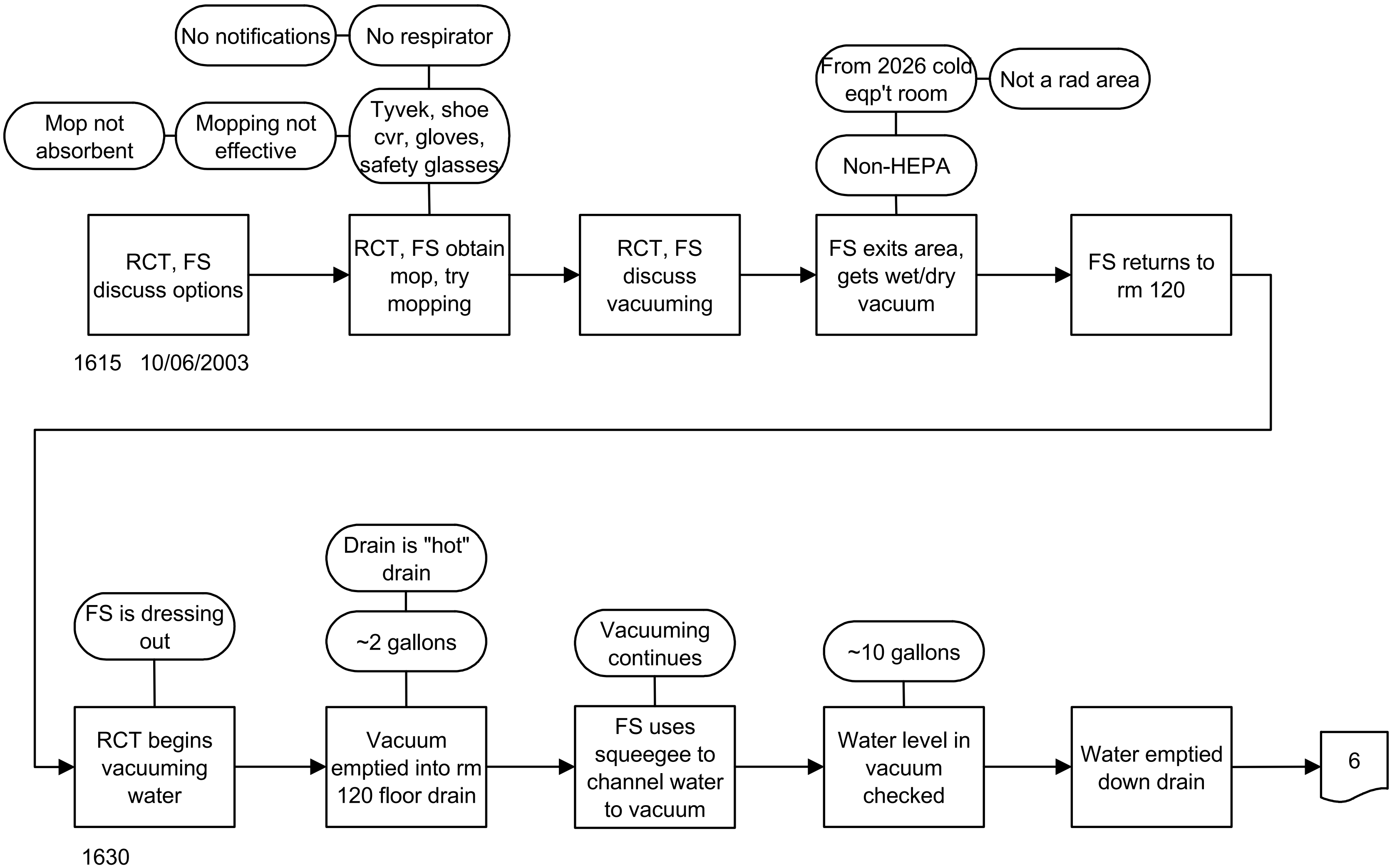
APPENDIX B. DETAILED TIME LINE

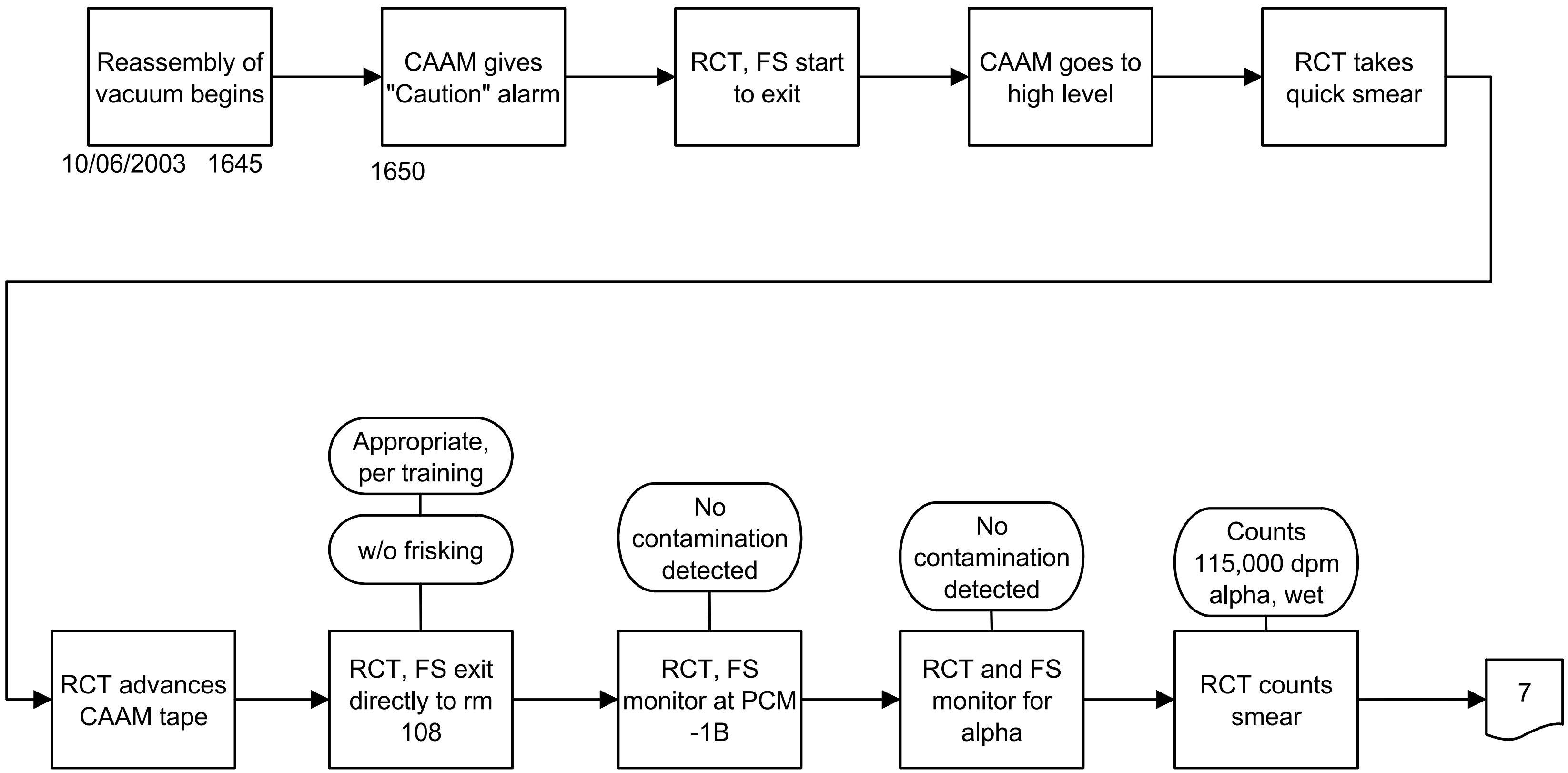

All cells, all labs
2" line, ~500 ft
BVLLLW upgrade completed
1990 - 1992
No foreign material exclusion
Open hole, no strainer
Drain becomes partially blocked, "slow"
~2000
Not fixed, no MJR
Not recorded, investigated
Pu-238 work begins in cell 3
Nov/Dec 2000
Same gage as Duratek
Indicator panel replaced for consistency
"sent" = "received"
No leak indication
New indicator further reveals "slow" drain
9 targets processed in 9 batches
Pu-238 target "batch" begins in cell 3
06/2003
Communicati on of expectations LTA
"Slow" drain not analyzed
RSS 567.1 and work instruction authorized
2-3 liters are normal volumes
Involves 5-10 gal of liquid
Dissolve 4 batches sources (1 at a time)
08/2003
Pu-238 processing ends
08/2003
Cell 3 cleanup (solid waste) begins
08/19/2003
2
Event, action
Condition
Causal factor

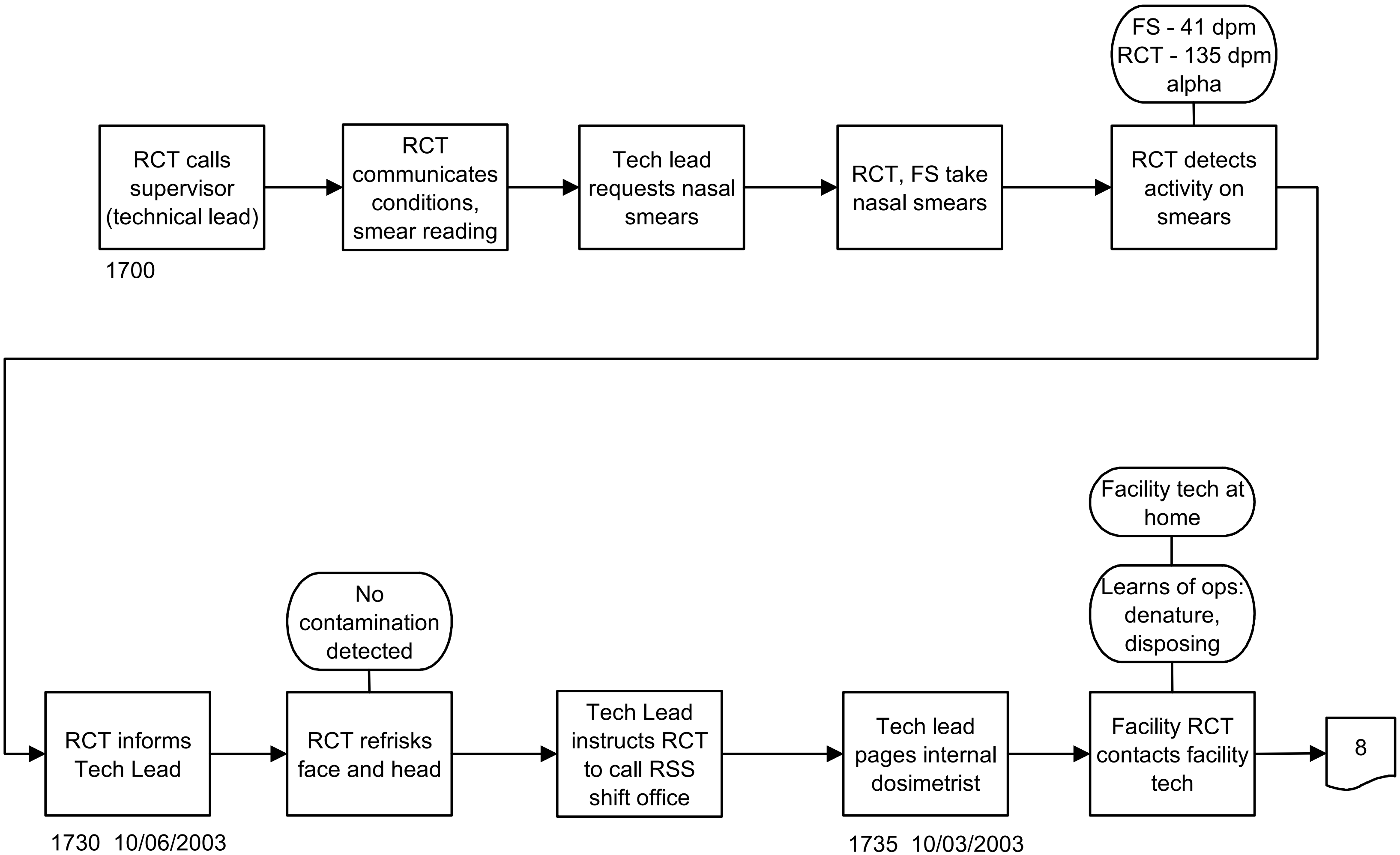

Prevents pressurization
Bottle cap is not tight
Cell3 cleanup ends
08/21/2003
Cell 3 manipulator breaks
09/11/2003
Cell 3 manipulator repair begins
09/19/2003
Pu-238 solution bottle knocked over during repair
09/19/2003
Pu-238 solution begins to enter cell 3 drain
NNFD tech returns to cell3
09/22/2003
NNFD tech observes overturned bottle, rights
09/22/2003
NNFD tech observes "stream" to drain
09/22/2003
Spill washed with 3 gallons water
09/24/2003
NNFD techs remove trash
09/24/2003
3

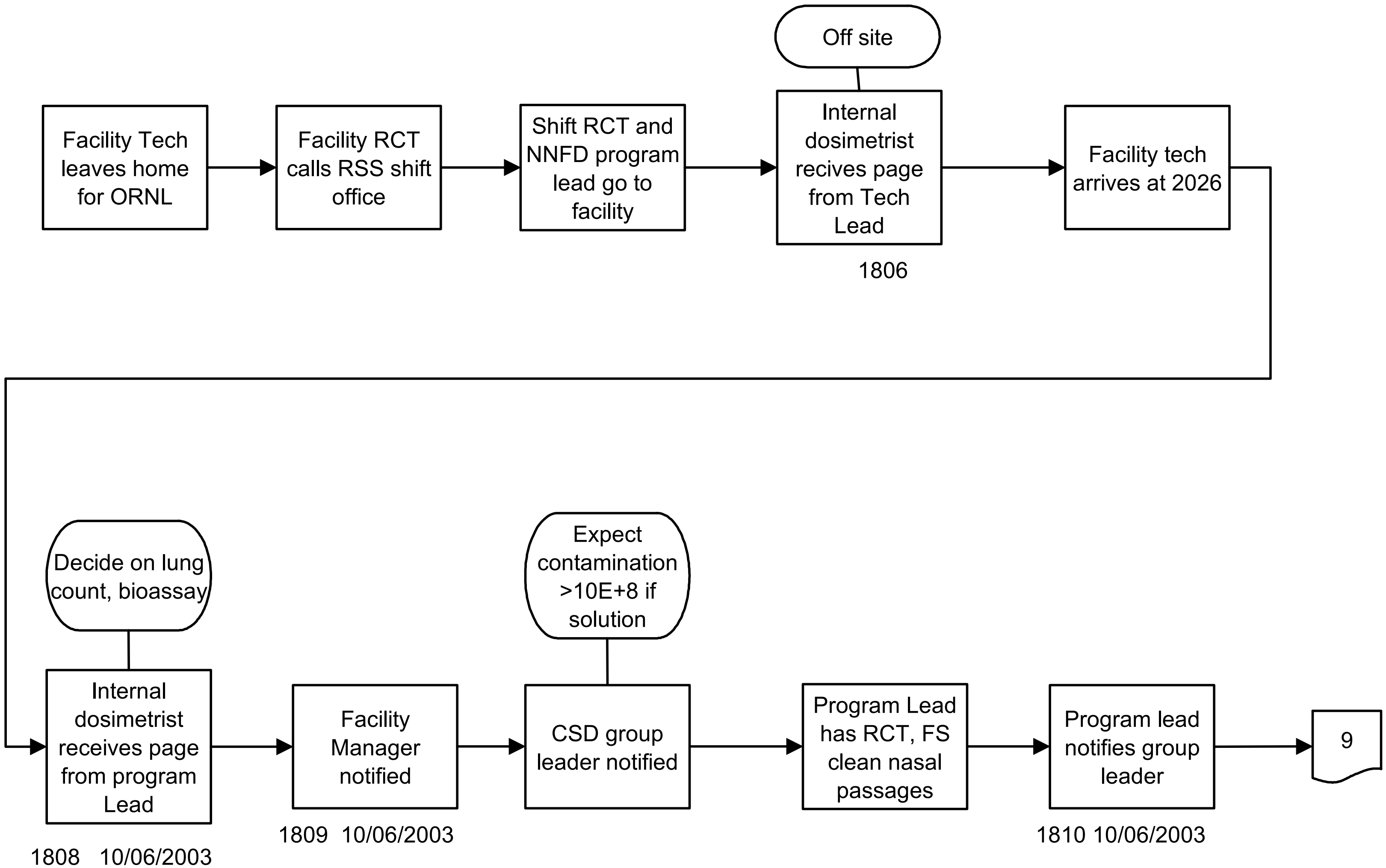

WOC d/n have indication
23 gal total from wash
Tank indication noticed at 2026
No records
40 gal volume w/slow drain not routine
Using brush to scrub
Leave overnight
Soln contains trace Pu-238
Discussed in POD
Listed as "routine ops"
NNFD techs rewash with 5 gal water
NNFD techs stopper drain, fill with 10 gal water
NNFD techs pour 7 ml dosimeter solution in drain
NNFD techs flush w/5 gal water
5th batch dissolution started
09/25/2003
09/25/2003
09/2003
2 people
To 5 gallon volume
Tilts container
5 gal process water
Dissolve 5th batch
Denature source liquid
Pour 5 gallons down drain
Fill container
Pour down drain
4
09/25/2003
~1215 10/06/2003

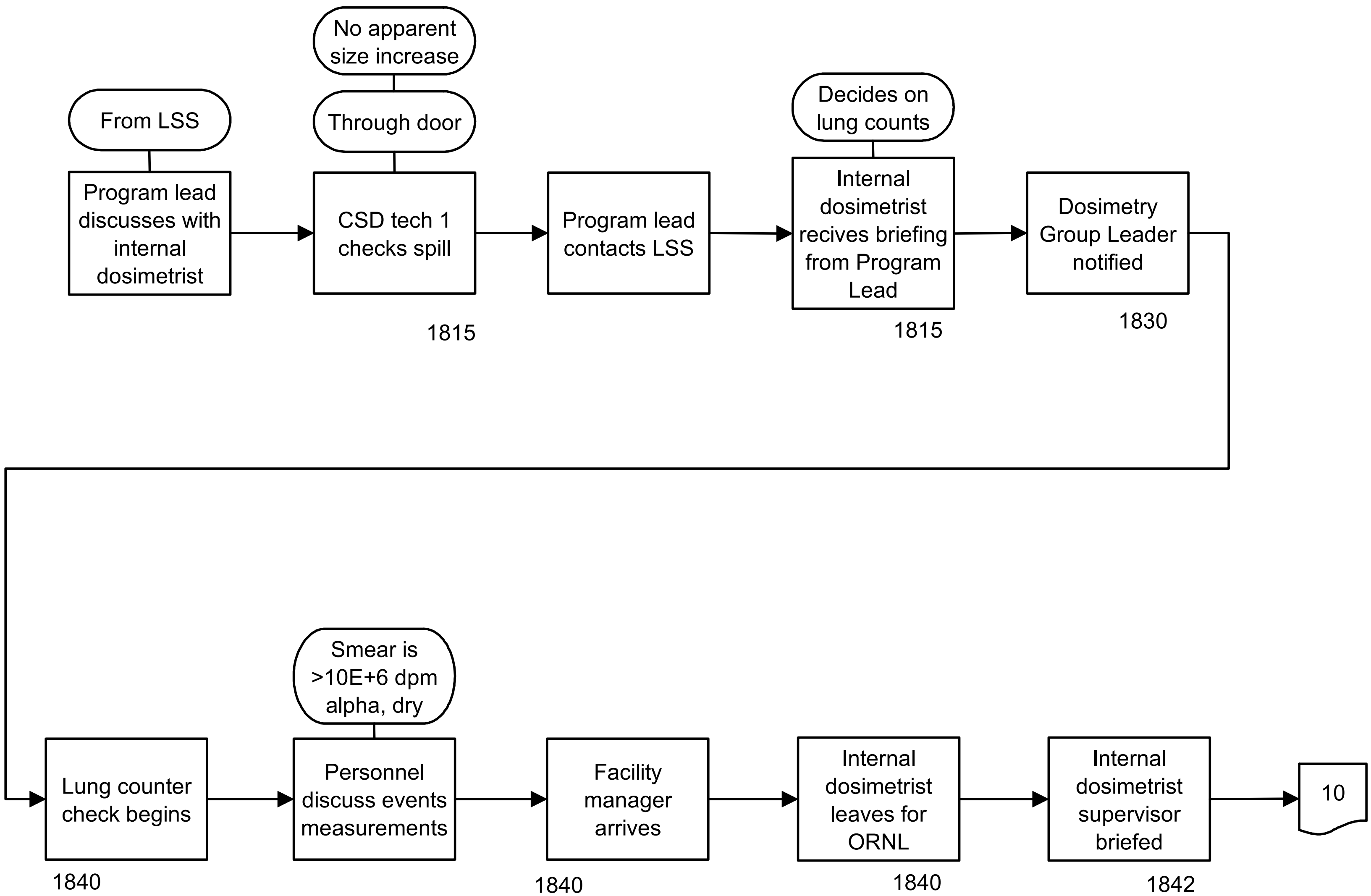

Drain capacity LT design
Flow exceeds capacity
Not visible
1 gal/min
Instruments show expected "slow" response
~30 gallons
No alarms
RWP and work package in place for routine entry
Lo vol
Begin rinsing drain with process water
Drain overflows
Finish drain rinse
1300 10/06/2003
Process water shut off
~1300 10/06/2003
RCT goes into rm 120 to change air filter
1600
RCT notices water on floor
Routine leaks into CA
Response guidance LTA
RWP allows decon
Unsure of material, ops
Conditions not recognized as abnormal
b-g instrument (no alpha)
No respirator
RCT exits
RCT notifies facility supervisor
1600 10/06/2003
FS, RCT return to room 120
1605 10/06/2003
RCT measures 20 - 30 k cpm b-g on water
RCT, FS exit area
5

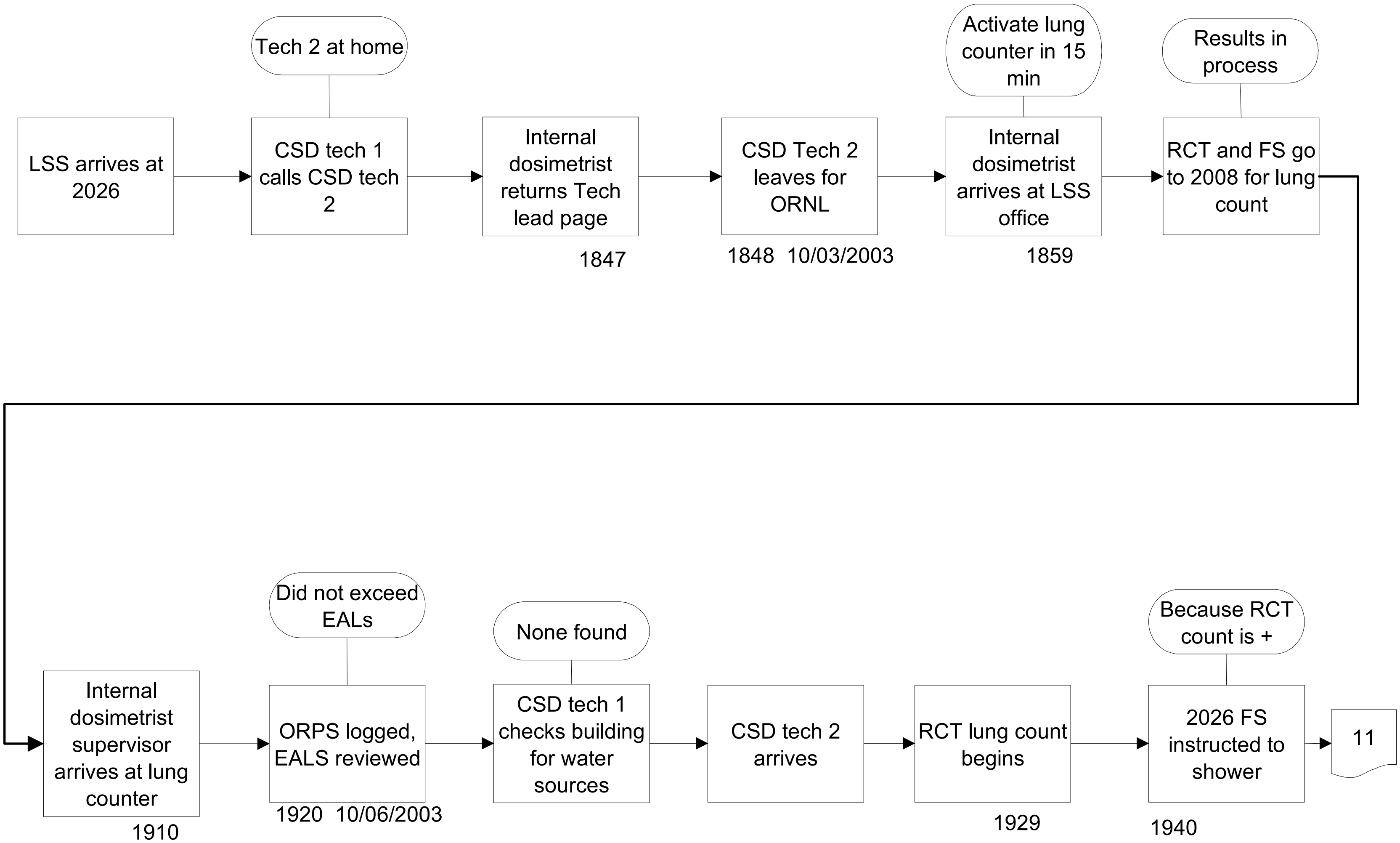

No notifications
No respirator
Mop not absorbent
Mopping not effective
Tyvek, shoe cvr, gloves, safety glasses
From 2026 cold eqp't room
Not a rad area
Non-HEPA
RCT, FS discuss options
RCT, FS obtain mop, try mopping
RCT, FS discuss vacuuming
FS exits area, gets wet/dry vacuum
FS returns to rm 120
1615 10/06/2003
Drain is "hot" drain
FS is dressing out
~2 gallons
Vacuuming continues
~10 gallons
RCT begins vacuuming water
Vacuum emptied into rm 120 floor drain
FS uses squeegee to channel water to vacuum
Water level in vacuum checked
Water emptied down drain
6
1630

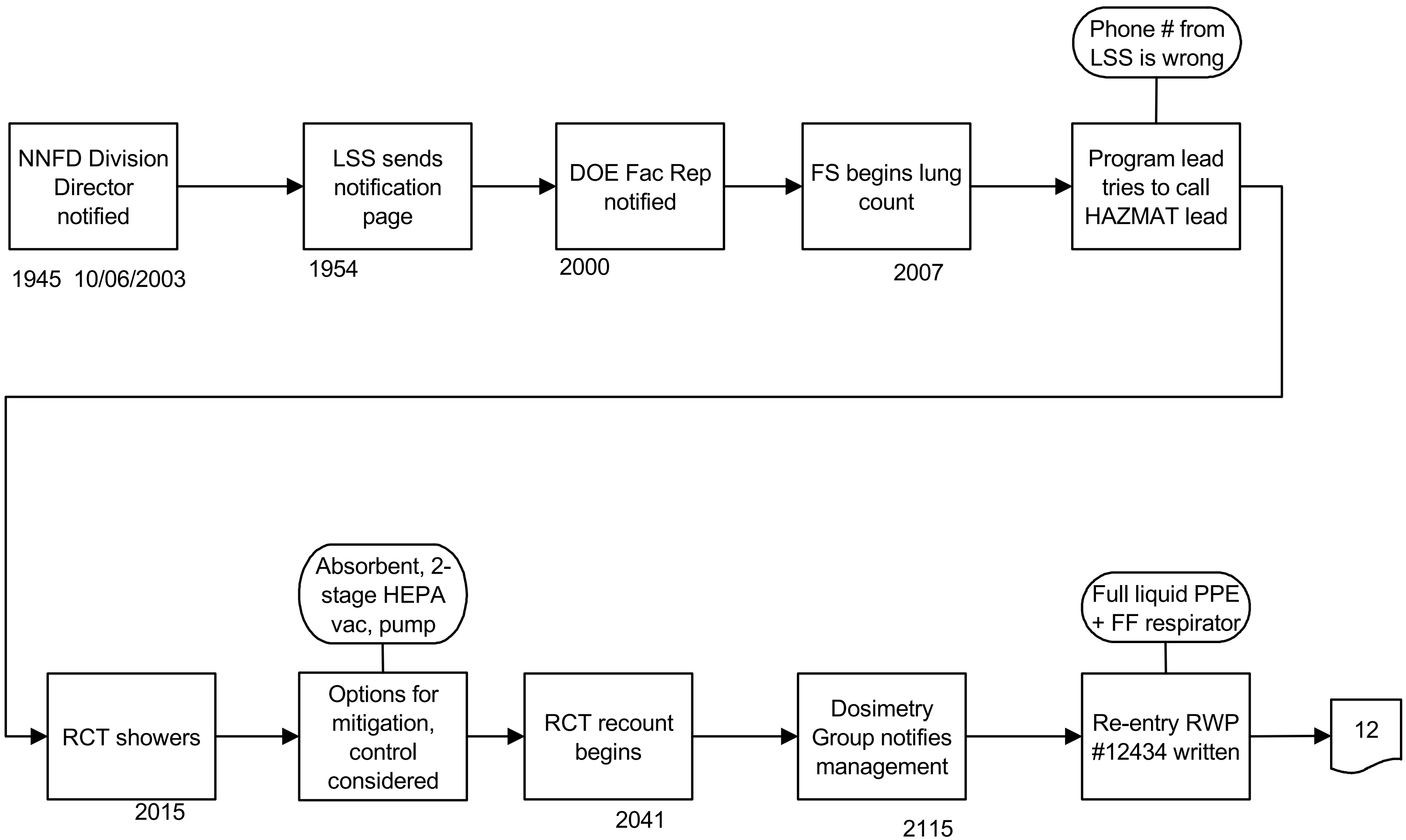

Reassembly of vacuum begins
10/06/2003 1645
CAAM gives "Caution" alarm
1650
RCT, FS start to exit
CAAM goes to high level
RCT takes quick smear
RCT advances CAAM tape
Appropriate, per training
w/o frisking
RCT, FS exit directly to rm 108
No contamination detected
RCT, FS monitor at PCM -1B
No contamination detected
RCT and FS monitor for alpha
Counts 115,000 dpm alpha, wet
RCT counts smear
7

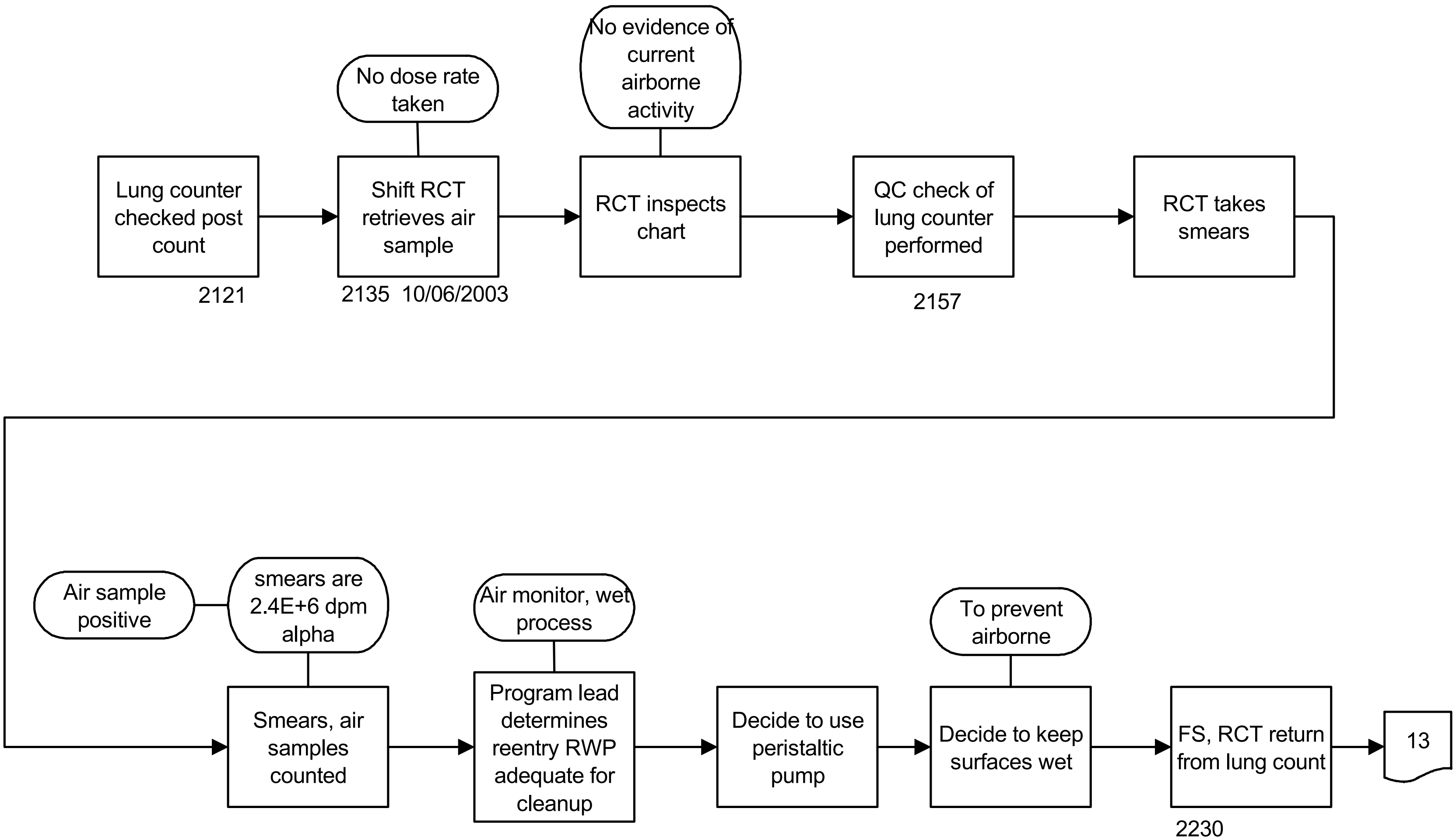

FS - 41 dpm
RCT - 135 dpm
alpha
RCT calls supervisor (technical lead)
1700
RCT communicates conditions, smear reading
Tech lead requests nasal smears
RCT, FS take nasal smears
RCT detects activity on smears
No contamination detected
Facility tech at home
Learns of ops: denature, disposing
RCT informs Tech Lead
1730 10/06/2003
RCT refrisks face and head
Tech Lead instructs RCT to call RSS shift office
Tech lead pages internal dosimetrist
1735 10/03/2003
Facility RCT contacts facility tech
8


Off site
Facility Tech leaves home for ORNL
Facility RCT calls RSS shift office
Shift RCT and NNFD program lead go to facility
Internal dosimetrist recives page from Tech Lead
1806
Facility tech arrives at 2026
Decide on lung count, bioassay
Expect contamination >10E+8 if solution
Internal dosimetrist receives page from program Lead
1808 10/06/2003
Facility Manager notified
1809 10/06/2003
CSD group leader notified
Program Lead has RCT, FS clean nasal passages
Program lead notifies group leader
1810 10/06/2003
9

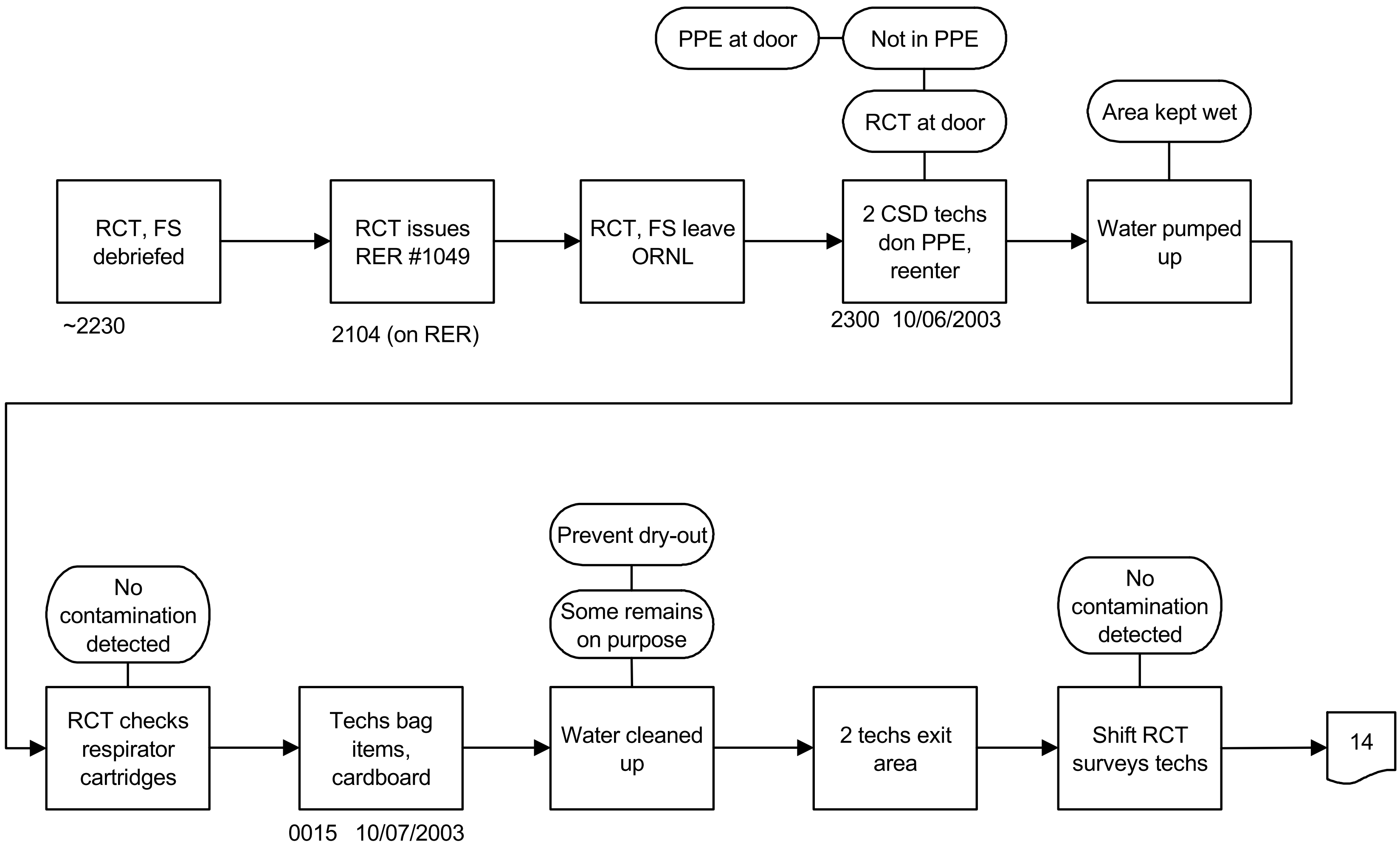

From LSS
Program lead discusses with internal dosimetrist
No apparent size increase
Through door
CSD tech 1 checks spill
1815
Program lead contacts LSS
Decides on lung counts
Internal dosimetrist recives briefing from Program Lead
1815
Dosimetry Group Leader notified
1830
Lung counter check begins
1840
Smear is >10E+6 dpm alpha, dry
Personnel discuss events measurements
Facility manager arrives
1840
Internal dosimetrist leaves for ORNL
1840
Internal dosimetrist supervisor briefed
1842
10

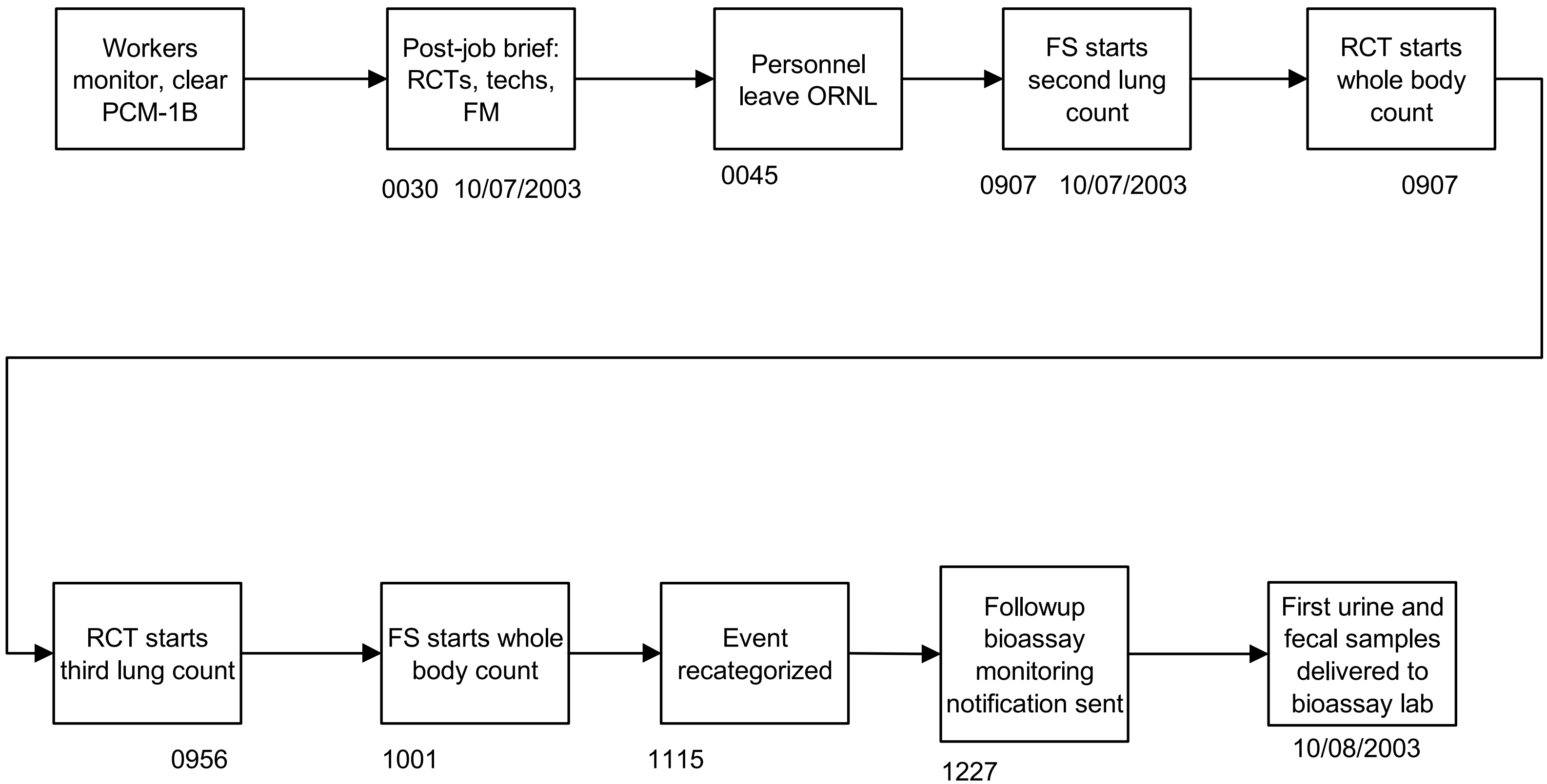

Tech 2 at home
Activate lung counter in 15 min
Results in process
LSS arrives at 2026
CSD tech 1 calls CSD tech 2
Internal dosimetrist returns Tech lead page
1847
CSD Tech 2 leaves for ORNL
1848 10/03/2003
Internal dosimetrist arrives at LSS office
1859
RCT and FS go to 2008 for lung count
Did not exceed EALs
None found
Because RCT count is +
Internal dosimetrist supervisor arrives at lung counter
1910
ORPS logged, EALS reviewed
1920 10/06/2003
CSD tech 1 checks building for water sources
CSD tech 2 arrives
RCT lung count begins
1929
2026 FS instructed to shower
1940
11


Phone # from LSS is wrong
NNFD Division Director notified
1945 10/06/2003
LSS sends notification page
1954
DOE Fac Rep notified
2000
FS begins lung count
2007
Program lead tries to call HAZMAT lead
Absorbent, 2-stage HEPA vac, pump
Full liquid PPE + FF respirator
RCT showers
2015
Options for mitigation, control considered
RCT recount begins
2041
Dosimetry Group notifies management
2115
Re-entry RWP #12434 written
12



No dose rate taken
No evidence of current airborne activity
Lung counter checked post count
2121
Shift RCT retrieves air sample
2135 10/06/2003
RCT inspects chart
QC check of lung counter performed
2157
RCT takes smears
Air sample positive
smears are 2.4E+6 dpm alpha
Air monitor, wet process
To prevent airborne
Smears, air samples counted
Program lead determines reentry RWP adequate for cleanup
Decide to use peristaltic pump
Decide to keep surfaces wet
FS, RCT return from lung count
2230
13


PPE at door
Not in PPE
RCT at door
Area kept wet
RCT, FS debriefed
~2230
RCT issues RER #1049
2104 (on RER)
RCT, FS leave ORNL
2 CSD techs don PPE, reenter
2300 10/06/2003
Water pumped up
Prevent dry-out
Some remains on purpose
No contamination detected
RCT checks respirator cartridges
Techs bag items, cardboard
0015 10/07/2003
Water cleaned up
2 techs exit area
No contamination detected
Shift RCT surveys techs
14


Workers monitor, clear PCM-1B
Post-job brief: RCTs, techs, FM
0030 10/07/2003
Personnel leave ORNL
0045
FS starts second lung count
0907 10/07/2003
RCT starts whole body count
0907
RCT starts third lung count
0956
FS starts whole body count
1001
Event recategorized
1115
Followup bioassay monitoring notification sent
1227
First urine and fecal samples delivered to bioassay lab
10/08/2003

APPENDIX C. REPORT OF THE MATERIAL ACCOUNTABILITY SUBGROUP

Report of the Material Accountability Subgroup

Subgroup Members:
Curtis Maples, Joe Herndon, Mike Borum, Kim Jeskie, John Keller, Chris Parks, Linda Gilpin, Julie Ezold (observer), Mark Robinson (observer).

Background:

As part of an initiative to consolidate ORNL nuclear facility operations, Laboratory management has decided to cease operation of the Building 3027 vault and deinventory this Category 2 nuclear facility. As one activity to support deinventory of the vault, ORNL is proceeding to terminate safeguards on 53 grams of high-radiation plutonium inappropriate for DOE to retain in long-term storage, and dispose of this plutonium as low level liquid waste. Prior to the event on October 6, four separate batches of plutonium had been dispositioned. These four batches had been denatured (^{232}Th added), diluted, and disposed of as low-level liquid waste from the Building 2026 hot cell 1. During these and previous evolutions, technicians noted the hot cell drains were "slow." During the fifth evolution of this activity, a batch (PU240AC) containing 38 grams of plutonium and 2 grams of Americium had also been denatured, diluted, and disposed of as low-level liquid waste from the Building 2026 hot cell 1. During the event investigated in this report, water was found behind cells 1, 2, and 3. The purpose of this subgroup was to review and determine the material accountability status of the plutonium in batch PU240AC.

Plutonium Disposition Project History:

The project for transfer of materials from the Building 3027 Vault to Building 2026 for denaturing, dilution, and disposal has been completed under the approved safeguards plan "Termination of Safeguards and Disposal of Materials from the 3027 Vault De-inventorying Activity," which was fully approved by both ORNL and ORO on June 25, 2003. In addition an "ORNL Wastewater Disposal Variance Request Form" was prepared for this project, and was fully approved by ORNL, Bechtel Jacobs, and ORO on July 1, 2003. This project was conducted under Chemical Sciences Division Research Safety Summary Number RSS 567.1 which was authorized on August 29, 2003, and under specific Work Instructions for each batch of material. The Work Instruction for batch PU240AC was approved by the CSD and the NNFD on July 11, 2003. The history of all batches processed to date is given in Table 1 below.

Table 1. Plutonium Disposition Batches

Batch	Date Received at 2026	Date Transferred to LLLW
1 & 2	July 14	August 1
3	August 6	August 19
4	August 20	Sept 4
5 (PU240AC)	September 9	October 6

Batch PU240AC was transferred from Material Balance Area 006 (Building 3027 Vault) to Material Balance Area 110 (Building 2026) on September 9 under an ORNL Nuclear Materials Intra-Laboratory Transfer Form (Transaction MC-17842) and entered into the Analytical Chemistry database as RMAL Request Number IPA1276.

Batch PU240AC was remotely dissolved, sampled, denatured and partially diluted from September 22 – 25 in cell 1. Sample results from the Pu Mass Spectrometry Analysis show that the Batch PU240AC plutonium was denatured to a 357/1 Th/Pu ratio, significantly exceeding the required ratio of 200/1 for Criticality Safety. This analysis was completed on September 25.

On September 30, ORNL NMCA was contacted by email for guidance on meeting the 1000/1 dilution requirement (to meet the requirements for the material attractiveness level) given a limit of a 5 gallon liquid container for mixing and dilution. Agreement was obtained by email on October 2, 2003 from both ORNL NMCA and the DOE Site Office that the dilution could be completed in a two step process, – initially diluted to 500/1 in the mixing container, the container emptied down the LLLW drain, and an additional 5 gallons of water added to the drain. A "Request for Authorization to Dispose of Nuclear Material" (number R1538) was approved by ORNL on October 2, 2003. A "Request for Authorization to Ship Nuclear Materials to Bechtel Jacobs Company, LLC" was approved on October 3, 2003.

On October 6, 2003, the 5 gallon solution of denatured plutonium was poured down the cell 1 LLLW drain, immediately followed by a 5 gallon water dilution meeting the dilution requirement. This was then followed by a 30 gallon water rinse. These activities were completed at 12:15 pm on October 6. A "ORNL Nuclear Materials Intra-Laboratory Transfer Form (Transaction MC-17671) was submitted on October 6 to transfer this material from MBA 110, to MBA 01 (Admin). This transfer was approved on October 6, 2003 and has been completed in the NMC&A Accountability System.

The accountability documentation demonstrates that all required approvals were received before transferring batch PU240AC to the LLLW system and into tank 1401 (F1401).

Event Followup:

After initial response to the event described in this report, sampling and analysis of the contents of tank 1401 and of the collected contaminated water from Room 120 were completed. These samples were analyzed to ascertain any further information to confirm that the plutonium from PU240AC actually reached tank 1401. Following is a discussion of those activities.

On October 7, prior to Duratek/BJC transferring the contents of tank 1401 to the Melton Valley Waste System, caustic was added to the tank, the tank was sparged for 30 minutes, and two samples were taken and analyzed. Also the contaminated water that was recovered from behind the cells in Room 120 was sampled and analyzed. Table 2 below summarizes the results.

Table 2. Sample analysis results

	HIP1068 (Ci)	274B (Ci)	SNM-82 (Ci)	SNM-222 (Ci)	PU240AC (Ci)	PU240AC % total	Total (Ci)
received	7/23/2003	7/23/2003	8/6/2003	8/21/2003	9/23/2003		
dumped	8/1/2003 12:30	8/1/2003 12:30	8/19/2003 8:30	9/4/2003 10:30	10/6/2003 12:15		
^{239}Pu	0.000	0.019	0.002	0.001	1.070	**99.71%**	1.073
^{240}Pu	0.456	1.370	0.011	0.030	4.560	**99.11%**	4.601
^{241}Pu	0.000	0.000	33.000	93.700	103.000	44.84%	229.700
^{242}Pu	0.000	0.000	0.000	0.000	0.000	0.00%	0.001
^{241}Am	0.000	0.000	4.420	10.200	6.120	29.51%	20.740

	F1401B (Bq/mL)	938 gal. F1401B (Ci)	% found	Wash F1401 (Bq/mL)	~400 gal. F1401 (Ci)	% found
$^{240+239}Pu$	29000	2.78	49.04%	1452	0.06	1.05%
^{241}Am	120000	11.51	55.52%	27000	1.10	5.33%

	Carboy (Bq/mL)	Carboy ~26.25 L (Ci)	% found	Vacuum (Bq/mL)	Vacuum ~26.25 L (Ci)	% found
$^{240+239}Pu$	53000	0.04	0.66%	35000	0.02	0.44%
^{241}Am	110000	0.08	0.38%	75000	0.05	0.26%

The sample results for Pu 239/240 from the Carboy and Vacuum containing contaminated water recovered from Room 120 after the event show that the liquid recovered from the floor contained very low concentrations of the material from PU240AC. The material on the floor is most likely from the 30 gallon flush that was completed after the diluted material was transferred to the LLLW system.

Based on the Pu 239/240 analyses performed on the two samples collected from tank 1401, 49.7% of the plutonium is indicated as having reached the tank for one sample (sample number 1401B). The other sample (1401A) resulted in 32% of the plutonium being located in the tank. Reliable sampling of the 1401 tank following the addition of caustic would not be expected. The plutonium and americium should have precipitated and would be expected to exist as a solid phase. The precipitated plutonium would be difficult to re-dissolve in acid. Thus, sampling of this two-phased system in tank 1401 would consist of mixing solids and water, and hoping that some degree of homogeneity could be obtained – a process that would not be expected to yield a high degree of accuracy. In addition, there are the uncertainties regarding the volume of the slurry in tank 1401 and whether representative aliquots from the two acquired analytical samples (likely to be a dilute suspensions themselves) before making acidic dissolutions. The bottom line is these samples should not be highly reliable for quantitative analyses. Given the above, achieving a realistic material balance confirmation from the analytical results using these alkaline samplings, or even having an agreement between the two analytical results obtained should not be expected. Figure 1 below accurately depicts the inhomogeniety of these samples (1401A and 1401B) and the difficulty in obtaining quantitative results.

Fig. 1. Tank Sample Photos

Tank 1401 still contained two previously disposed batches of material (batches 3 and 4). The analytical results for plutonium 239/240 may be considered the most reliable indicator of the material being disposed of on October 6th, given the isotopic distribution of that sample compared to those for previous disposed plutonium materials. In contrast, the americium (Am-241) analyses must be considered in terms of total americium from three disposals, not just the October 6th disposal. With americium, balance of 56% (1401B) and 40% (1401A) were indicated for this isotope (sum of americium in the disposed batches).

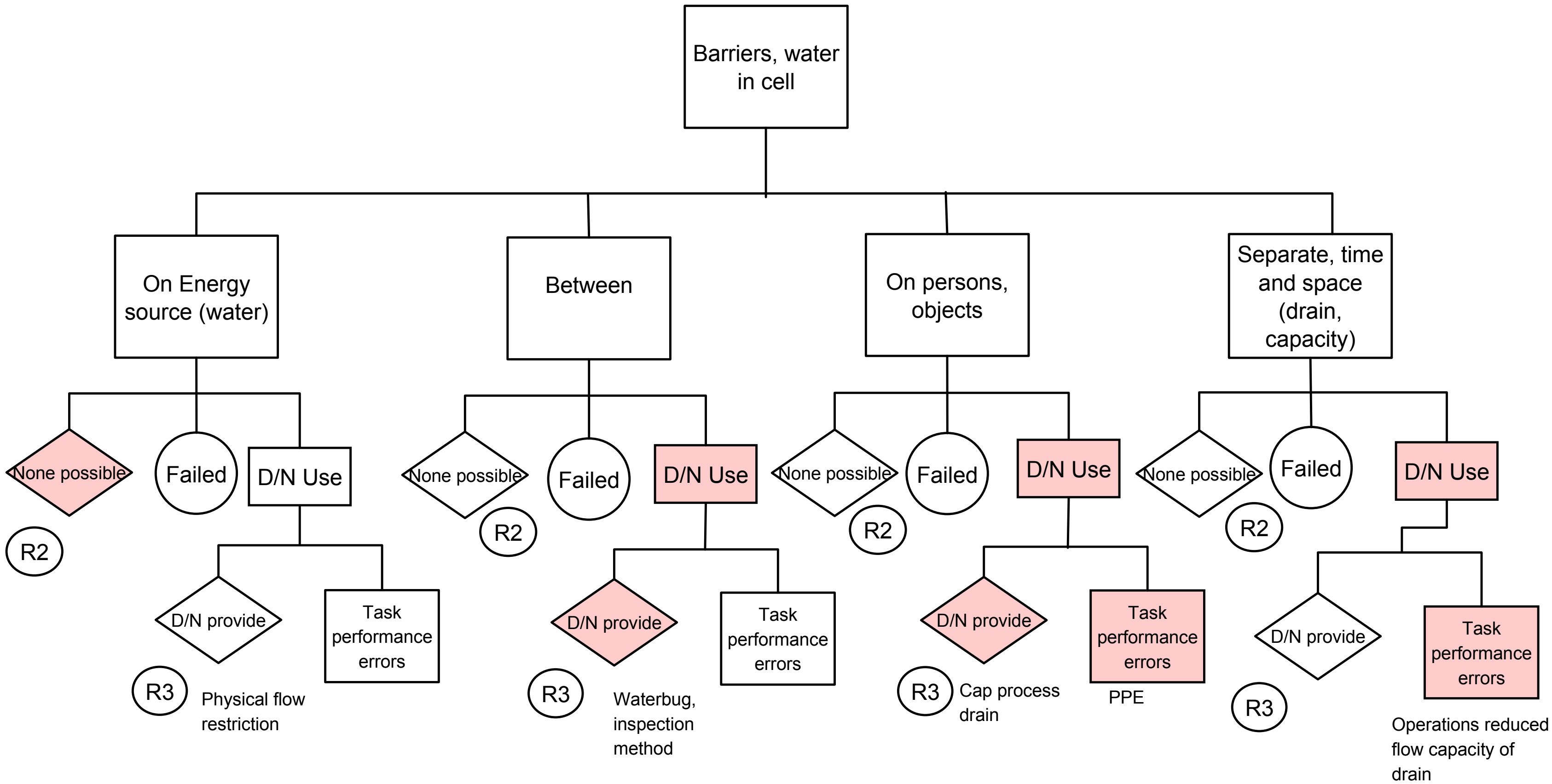
Additionally, results for Th-232 (the denaturing agent-the fifth batch disposal made a large contribution in the tank contents, approximately 20 kg), ~80 % of the expected Th-232 is found in tank 1401. Based on the Pu-242 isotope found by mass spectrometry in the fifth batch prior to disposal~ 79.7% is found in the tank samples.

In addition to analytical activities, extensive review of the records from the Duratek/BJC Waste Operations Center (WOC) was conducted to ascertain any addition information to confirm that the plutonium from PU240AC actually reached tank 1401. Data from the Duratek WOC shows that over the time period of October 6 – October 7 approximately 100 gallons of liquids were transferred to tank 1401. While that amount exceeds the quantity input into the system on October 6, it does account for the material transferred and possible holdup from cell 3 as described in this investigation report. No other conclusions could be obtained from review of the WOC tank level data.

Conclusions:

The accountability team has concluded from the materials and data reviewed that the special nuclear material identified as PU240AC was denatured and diluted as required and the requirements for termination of safeguards and disposal as LLLW have been met. The PU240AC material was fully denatured in excess of requirements, the required dilutions were in fact made by the two operations technicians, and only very small quantities of fully denatured and fully diluted plutonium were present in the water which was recovered behind the cells in Room 120. The resulting solutions could only physically be in Five locations, namely in tank 1401 (since jetted downstream in the LLLW system), in the piping between the lower pans and the tank, in the cell 1 lower pan in the process drain system, or in the contaminated water behind the cell. The quantitative data from the contaminated water analysis demonstrates only ~1% of the material was in this water, all of which was recovered, except that lost to evaporation, and dispositioned back to the LLLW system. Cell entries were made to both cell 1 and cell 3 during this investigation, and no residual liquid was found in either of these pans. Only dry surface residue could possibly remain in these pans. In addition, the LLLW piping plug was opened during this investigation and any remaining holdup in the piping was discharged to tank 1401. ORNL has pursued all available options to ensure the appropriate disposition of the material. This committee also concludes that the material from batch PU240AC has been properly dispositioned to the LLLW system, and the ORNL NMC&A group agrees with this conclusion.

APPENDIX D. BARRIER ANALYSIS



Barriers, water in cell
On Energy source (water)
Between
On persons, objects
Separate, time and space (drain, capacity)
None possible
Failed
D/N Use
R2
None possible
Failed
D/N Use
R2
None possible
Failed
D/N Use
R2
None possible
Failed
D/N Use
R2
D/N provide
Task performance errors
R3
Physical flow restriction
D/N provide
Task performance errors
R3
Waterbug, inspection method
D/N provide
Task performance errors
R3
Cap process drain
PPE
D/N provide
Task performance errors
R3
Operations reduced flow capacity of drain

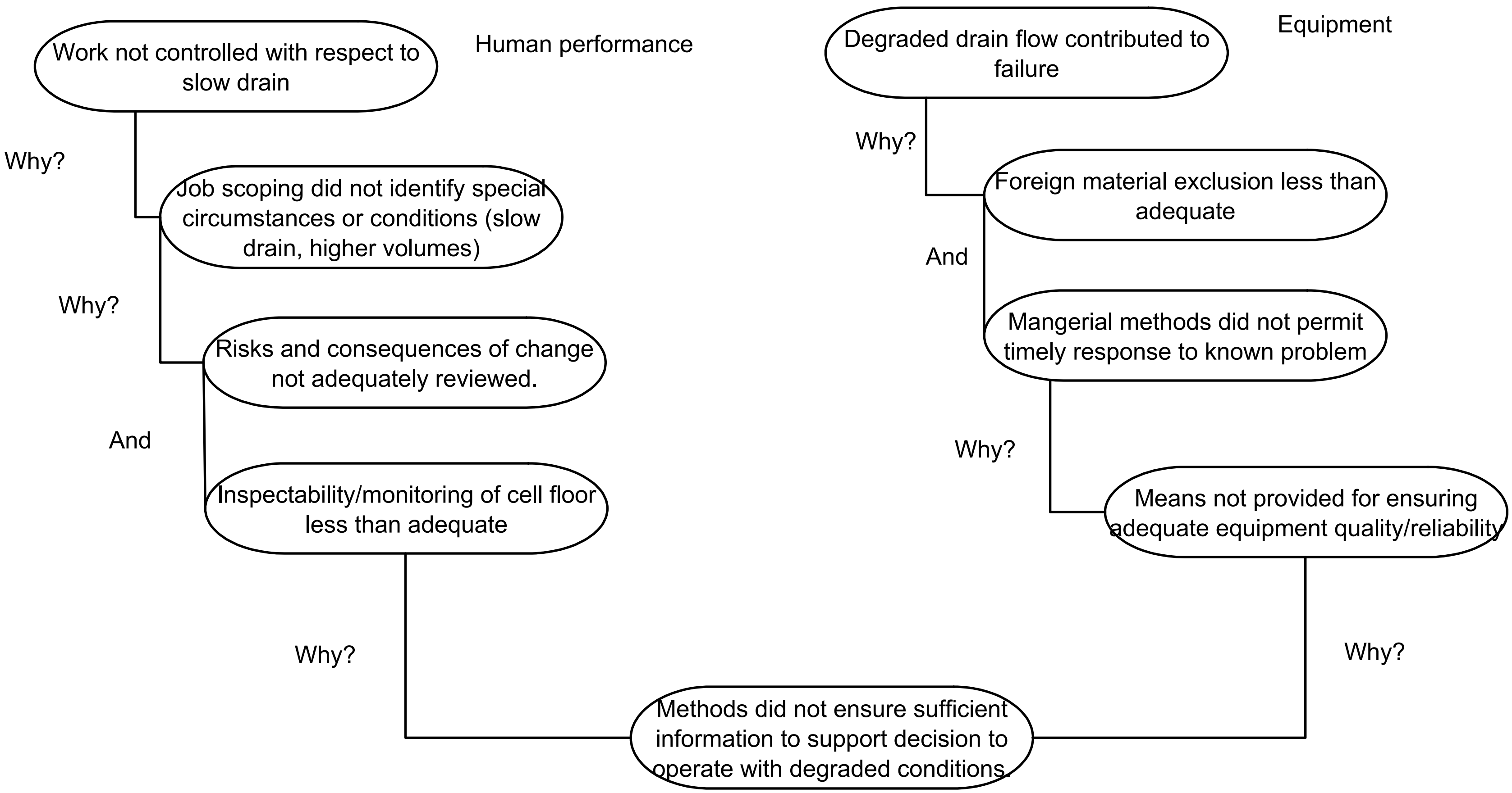
APPENDIX E. CHANGE ANALYSIS

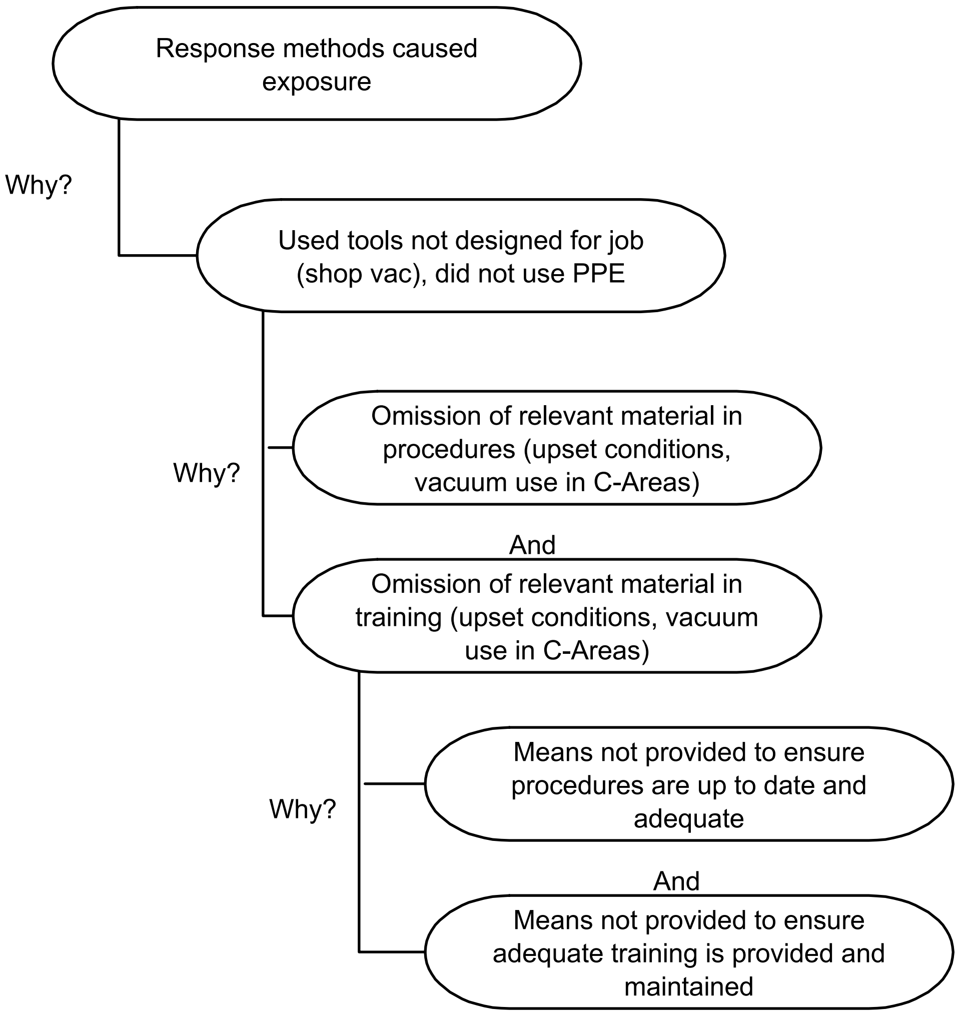
Change Analysis Worksheet

Factors	Accident Situation	Prior, Ideal, or Accident-free Situation	Differences	Evaluation or Effect
What Conditions, occurrences, activities, equipment	Approximately 40 gallons of water utilized in batch 5.	Approximately 10 gallons of water utilized for batches 1-4.	Batch 5 of material was larger requiring additional water to dilute the material and flush the system.	Significantly more water was poured down the drain increasing possibility of overflow.
	Drains noted to be "slow" for cells 1-3.	No notable delay in drainage for cells 4-6 or for laboratory hot drains.	Past operational history indicates possibility that materials were inadvertently released down drains	Possibility that drain has become partially blocked by foreign objects or material build-up.
	LLLW Tank Indicator not showing timely increase consistent with volume of materials being poured down drain.	LLLW Tank Indicator shows percentage increase consistent with volume of materials poured down drain.	Technicians have little confidence that instrumentation represents a true indication of equipment status.	Could indicate malfunctioning or damaged indicator or partially blocked drain.
	Use of 5 gallon glass cylinder for denaturing/ dissolution work	Use of smaller, easier to handle material containers	5 gallon glass cylinder is difficult to maneuver and control for pouring, etc.	Possibility of overflowing or loss of control of materials.
WHEN Occurred, identified, facility status, schedule	During regular shift	During regular shift	None.	No changes were noted related to time of occurrence.
WHERE Physical location, environmental conditions	Hot cell 1-3	Hot cells 4-6	Hot cells 1-3 have been the location of several past work evolutions involving pouring dissolved materials down the drain. Problems with dissolution of metals were identified in hot cell 1.	Possibility that past operations in hot cells have blocked the drain with foreign objects or materials.

Factors	Accident Situation	Prior, Ideal, or Accident-free Situation	Differences	Evaluation or Effect
WHO Staff involved, training, qualification, supervision	Experienced RCT New Facility Supervisor Experienced Technicians	Same staff	None.	No changes were noted related to staff involved.
HOW Control chain, hazard analysis monitoring	Work control process utilized for material disposition activities.	Work control process utilized for material analysis activities.	Material disposition is not the primary mission of building 2026 hot cells although it is allowed in safety basis documentation.	Material disposition required significantly greater amounts of materials to be poured down the drain increasing opportunity for overflow.

APPENDIX F. CAUSAL FACTORS ANALYSIS


Work not controlled with respect to slow drain
Human performance
Why?
Job scoping did not identify special circumstances or conditions (slow drain, higher volumes)
Why?
Risks and consequences of change not adequately reviewed.
And
Inspectability/monitoring of cell floor less than adequate
Why?
Degraded drain flow contributed to failure
Equipment
Why?
Foreign material exclusion less than adequate
And
Mangerial methods did not permit timely response to known problem
Why?
Means not provided for ensuring adequate equipment quality/reliability
Why?
Methods did not ensure sufficient information to support decision to operate with degraded conditions.


Response methods caused exposure
Why?
Used tools not designed for job (shop vac), did not use PPE
Why?
Omission of relevant material in procedures (upset conditions, vacuum use in C-Areas)
And
Omission of relevant material in training (upset conditions, vacuum use in C-Areas)
Why?
Means not provided to ensure procedures are up to date and adequate
And
Means not provided to ensure adequate training is provided and maintained

APPENDIX G. ROOT CAUSE ANALYSIS

Causal Analysis Tree Rev. 0

START HERE

A1 Design/ Engineering Problem

B1 DESIGN INPUT LTA
- C01 Design input cannot be met
- C02 Design input obsolete
- C03 Design input not correct
- C04 Necessary design input not available

B2 DESIGN OUTPUT LTA
- **C01 Design output scope LTA**
- C02 Design output not clear
- C03 Design output not correct
- C04 Inconsistent design output
- C05 Design input not addressed in design output
- C06 Drawing, specification, or data error
- C07 Error in equipment or material selection
- **C08 Errors not detectable**
- C09 Errors not recoverable

B3 DESIGN/ DOCUMENTATION LTA
- C01 Design/documentation not complete
- C02 Design/documentation not up to date
- C03 Design/documentation not controlled

B4 DESIGN/ INSTALLATION VERIFICATION LTA
- C01 Independent review of design/documentation LTA
- C02 Testing of design/ installation LTA
- C03 Independent inspection of design/ installation LTA
- C04 Acceptance of design/installation LTA

B5 OPERABILITY OF DESIGN/ ENVIRONMENT LTA
- C01 Ergonomics LTA
- **C02 Physical environment LTA**
- C03 Natural environment LTA

A2 Equipment/ Material Problem

B1 CALIBRATION FOR INSTRUMENTS LTA
- C01 Calibration LTA
- C02 Equipment found outside acceptance criteria

B2 PERIODIC/ CORRECTIVE MAINTENANCE LTA
- C01 Preventive maintenance for equipment LTA
- C02 Predictive maintenance LTA
- C03 Corrective maintenance LTA
- C04 Equipment history LTA

B3 INSPECTION/ TESTING LTA
- C01 Start-up testing LTA
- C02 Inspection/testing LTA
- C03 Post-maintenance/ Post- modification testing LTA

B4 MATERIAL CONTROL LTA
- C01 Material handling LTA
- C02 Material storage LTA
- C03 Material packaging LTA
- C04 Material shipping LTA
- C05 Shelf life exceeded
- C06 Unauthorized material substitution
- C07 Marking/labeling LTA

B5 PROCUREMENT CONTROL LTA
- C01 Control of changes to procurement specifications/ purchase order LTA
- C02 Fabricated item did not meet requirements
- C03 Incorrect item received
- C04 Product acceptance requirements LTA

B6 DEFECTIVE, FAILED OR CONTAMINATED
- C01 Defective or failed part
- C02 Defective or failed material
- C03 Defective weld, braze or soldering joint
- C04 End of life failure
- C05 Electrical or instrument noise
- **C06 Contaminant**

A3 Human Performance LTA

B1 SKILL BASED ERROR
- C01 Check of work was LTA
- C02 Step was omitted due to distraction
- C03 Incorrect performance due to mental lapse
- C04 Infrequently performed steps are performed incorrectly
- C05 Delayin time cause LTA actions
- C06 Wrong action selected based on similarity with other actions
- C07 Omission/repeating of steps due to assumptions for completion

B2 RULE BASED ERROR
- C01 Strong rule incorrectly chosen over other rules
- C02 Signs to stop are ignored and step performed incorrectly
- C03 Too much activity is occurring and error made in problem solving
- C04 Previous success in use of rule reinforces continued use of rule
- C05 Situation incorrectly identified or represented resulting in wrong rule used

B3 KNOWLEDGE BASED ERROR
- C01 Attention was given to wrong issues
- C02 LTA conclusion based on sequencing of facts
- C03 Individual justified action by focusing on biased evidence
- C04 LTA review based on assumption that process will not change
- C05 Incorrect assumption that a correlation existed between two or more facts
- **C06 Individual underestimated the problem by using past events as basis**

B4 WORK PRACTICES LTA
- C01 Individual's capability to perform work LTA [Examples include: Sensory/perceptual capabilities LTA, Motor/physical capabilities LTA, and Attitude/ psychological profile LTA.]
- C02 Deliberate violation

A4 Management Problem

B1 MANAGEMENT METHODS LTA
- **C01 Management policy guidance/ expectations not well-defined, understood or enforced**
- **C02 Job performance standards not adequately defined**
- C03 Management direction created insufficient awareness of impact of actions on safety/reliability
- C04 Management follow-up or monitoring of activities did not identify problems
- **C05 Management assessment did not determine causes of previous event or known problem**
- C06 Previous industry or in-house experience was not effectively used to prevent recurrence
- C07 Responsibility of personnel not well-defined or personnel not held accountable
- C08 Corrective action responses to a known or repetitive problem was untimely
- C09 Corrective action for previously identified problem or event was not adequate to prevent recurrence

B2 RESOURCE MANAGEMENT LTA
- C01 Too manyadministrative duties assigned to immediate supervisor
- C02 Insufficient supervisory resources to provide necessary supervision
- C03 Insufficient manpower to support identified goal/objective
- C04 Resources not provided to assure adequate training is provided/ maintained
- C05 Needed resource changes not approved/funded
- C06 Means not provided to assure procedures/documents/records were of adequate quality and up to date
- C07 Means not provided for assuring adequate availability of appropriate materials/tools
- **C08 Means not provided for assuring adequate equipment quality, reliability, or operability**
- C09 Personnel selection did not assure match of worker motivations/job descriptions
- C10 Means/method not provided for assuring adequate quality of contract services

B3 WORK ORGANIZATION & PLANNING LTA
- C01 Insufficient time for worker to prepare task
- C02 Insufficient time allotted for task
- C03 Duties not well-distributed among personnel
- C04 Too few workers assigned to task
- C05 Insufficient number of trained or experienced workers assigned to task
- C06 Planning not coordinated with inputs from Walk downs/task analysis
- C07 Job scoping did not identify potential task interruptions and/or environmental stress
- **C08 Job scoping did not identify special circumstances and/or conditions**
- **C09 Work planning not coordinated with all departments involved in task**
- C10 Problem performing repetitive tasks and/or subtasks
- C11 Inadequate work package preparation

B4 SUPERVISORY METHODS LTA
- C01 Tasks and individual accountability not made clear to worker
- C02 Progress/status of task not adequately tracked
- C03 Appropriate level of in-task supervision not determined prior to task
- C04 Direct supervisory involvement in task interfered with overview role
- C05 Emphasis on schedule exceeded emphasis on methods/doing a good job
- C06 Job performance and self-checking standards not properly communicated
- C07 Too many concurrent tasks assigned to worker
- C08 Frequent job or task "shuffling"
- C09 Assignment did not consider worker's need to use higher order skills
- C10 Assignment did not consider worker's previous task
- C11 Assignment did not consider worker's ingrained work patterns
- C12 Contact with personnel too inflequent to detect work habit/attitude changes
- C13 Provided feedback on negative performance but not on positive performance

B5 CHANGE MANAGEMENT LTA
- C01 Problem identification did not identify need for change
- C02 Change not implemented in timelymanner
- C03 Inadequate vendor support of change
- C04 Risks/consequences associated with change not adequately reviewed/assessed
- C05 System interactions not considered
- C06 Personnel/department interactions not considered
- C07 Effects of change on schedules not adequately addressed
- C08 Change related training/retraining not performed or not adequate
- C09 Change related documents not developed or revised
- C10 Change related equipment not provided or not revised
- C11Changes not adequatelycommunicated
- C12 Change not identifiable during task
- C13 Accuracy/effectiveness of change not verified or not validated

A5 Communications LTA

B1 WRITTEN COMMUNICATIONS METHOD OF PRESENTATION LTA
- C01 Format deficiencies
- C02 Improper referencing or branching
- C03 Checklist LTA
- C04 Deficiencies in user aids (charts, etc.)
- C05 Recent changes not made apparent to user
- C06 Instruction step/ information in wrong sequence
- C07 Unclear/complex wording or grammar

B2 WRITTEN COMMUNICATION CONTENT LTA
- C01 Limit inaccuracies
- C02 Difficult to implement
- C03 Data/computations wrong/incomplete
- C04 Equipment identification LTA
- C05 Ambiguous instructions/ requirements
- C06 Typographical error
- C07 Facts wrong/ requirements not correct
- C08 Incomplete/situation not covered
- C09 Wrong revision used

B3 WRITTEN COMMUNICATION NOT USED
- C01 Lack of written communication
- C02 Not available or inconvenient for use

B4 VERBAL COMMUNICATION LTA
- **C01 Communication between work groups LTA**
- C02 Shift communications LTA
- C03 Correct terminology not used
- C04 Verification/repeat back not used
- C05 Information sent but not understood
- C06 Suspected problems not communicated to supervision
- C07 No communication method available

A6 Training Deficiency

B1 NO TRAINING PROVIDED
- C01 Decision not to train
- C02 Training requirements not identified
- C03 Work incorrectly considered "skill of the craft"

B2 TRAINING METHODS LTA
- C01 Practice or hands on experience LTA
- C02 Testing LTA
- C03 Refresher training LTA
- C04 Inadequate presentation

B3 TRAINING MATERIAL LTA
- C01 Training objectives LTA
- C02 Inadequate content
- C03 Training on new work methods LTA
- C04 Performance standards LTA

A7 Other Problem

B1 EXTERNAL PHENOMENA
- C01 Weather or ambient conditions LTA
- C02 Power failure or transient
- C03 External fire or explosion
- C04 Other natural phenomena LTA

B2 RADIOLOGICAL/HAZARDOUS MATERIAL PROBLEM
- C01 Legacy contamination
- C02 Source unknown

LTA = Less than Adequate

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