U.S. DEPARTMENT OF ENERGY | Office of Science

Incident Investigation Report

Spontaneous Ignition of Natural Uranium Metal at Argonne National Laboratory on November 27, 2017

January 2018

U.S. DEPARTMENT OF ENERGY | Office of Science

Spontaneous Ignition of Natural Uranium Metal at Argonne National Laboratory on November 27, 2017

Incident Investigation Report

Approved by:

Juston Fontaine
Acting Associate Deputy Director for Field Operations
Office of Science
U.S. Department of Energy
Investigation Team Leader

on behalf of:

Roger Snyder Pacific Northwest Site Office Manager Office of Science U.S. Department of Energy Team Co-Leader	Paul Golan Berkeley Site Office Manager Office of Science U.S. Department of Energy Team Co-Leader
Joanna Serra Acting Senior Nuclear Safety Advisor Office of Science U.S. Department of Energy	Hank Kloeckler Fire Protection Engineer National Nuclear Security Administration U.S. Department of Energy
Suellen Cook Incident Investigations Manager Argonne National Laboratory	David Cecala Materials Processing Section Manager Y-12 National Security Complex
Katherine Martin Senior Manager, Production Integration Y-12 National Security Complex	Alisa Haller EHS&S Specialist Pacific Northwest National Laboratory
Daniel Middleton General Engineer Office of Science U.S. Department of Energy	

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Incident Description

On November 27, 2017, a fire began in samples of natural uranium metal located in a storage vault in Building 350 at Argonne National Laboratory (ANL). At 12:08 a.m., the Argonne Fire Department was dispatched after a smoke alarm was set off in Room C-068A. Inside the vaulted room, firefighters were met with thick smoke. Using a thermal imaging camera, flames of approximately two feet were seen coming from the top and left side of a cabinet across the room. After using an extinguisher to knock down the flames, firefighters then layered Lith-X, a dry powder extinguishing agent, over the top of the material that was burning. At approximately 12:35 a.m., the fire was out.

After the immediate emergency had been stabilized, a decision was made by ANL to place the remnants of the 48 containers of natural uranium that were involved in the fire into a consolidated and safer configuration. At 3:53 p.m., equipped with Personal Protective Equipment (PPE) and self-contained breathing apparatus (SCBA), firefighters re-entered the affected area. The pile of burned material was slowly scraped off the cabinet shelf and placed in a 30-gallon drum, surrounded by layers of Lith-X. The following day, Tuesday, November 28, four samples of similar material from an adjacent room were placed in pint size cans lined with Lith-X. The cans were then added to the drum with the previously inserted burned material.

No injuries or worker contamination occurred during the initial fire response and follow-up actions. Radiological contamination surveys and air sampling showed that any radioactive airborne contamination generated during the fire was contained within the HEPA filter system and did not spread to any outside or surrounding facilities.

Background

Argonne National Laboratory traces its origins to the Manhattan Project and the effort to create the world's first self-sustaining nuclear reaction. It was formally chartered as Argonne National Laboratory on July 1, 1946, and began developing nuclear reactors for the nation's peaceful nuclear energy program. Today, with an annual operating budget of more than $750 million and a workforce that includes approximately 3,200 employees, ANL is a multidisciplinary science and engineering research center, executing a diverse research agenda in areas of material science, chemistry, biology, mathematics and high performance computing.

Building 350 was formerly the location for the New Brunswick Laboratory (NBL), a Government Owned, Government Operated facility that operated independently of ANL, but utilized ANL services. Established in 1949, NBL's initial mission was to provide a Federal capability for the assay of uranium-containing materials for the nation's developing atomic energy program. NBL was relocated from New Jersey to the site at ANL in the mid-1970s.

As a result of programmatic and nuclear safety concerns, in May of 2016, NBL underwent a reorganization to adopt a new business model that allowed the organization to continue its mission to produce, sell, and deliver certified reference materials (CRM) in a more efficient, effective, and sustainable manner. The reorganization initially separated NBL into two Federal organizations, a program office and a facility transition office. The NBL Program Office was tasked with fulfilling NBL's core missions to provide reliable, high-quality CRMs using other DOE laboratories for the production, storage and distribution of nuclear materials. The Building 350 Transition Office was tasked with preparing the facility for the transition to ANL, which would subsequently oversee de-inventory and repurposing of the facility. As such, the Transition Office worked in partnership with ANL to reduce the nuclear footprint, concentrating efforts on de-inventory to meet ANL and DOE minimum requirements for a less than Hazard Category-3 facility, prior to the facility being transitioned to ANL in April 2017.

The material involved in the fire was naturally occurring uranium metal (U238 ~99.3%/U235 ~0.7%). In total, there were 52 containers of this material stored in Building 350, 48 of which were involved in the fire, each containing approximately 500 grams. The material was labeled as uranium shot and was believed to be packaged in the mid-1960s at NBL in New Jersey and subsequently transferred to the new NBL site at Argonne in 1977.

Causal Analysis

Direct Cause: The direct cause (DC) of an accident is the immediate event or condition that caused the accident. In this case, the event that immediately caused the fire in Building 350 was determined to be:

DC: Finely divided natural uranium, that is susceptible to a pyrophoric reaction, was exposed to oxygen and/or moisture, potentially developed uranium hydride, resulting in ignition leading to combustion of the material.

Contributing Causes: Contributing causes (CC) are events or conditions that, collectively with other causes, increased the likelihood of an accident, but which individually did not cause the accident. These conditions or events, if not mitigated, increase the probability of similar accidents in the future. In this instance, the contributing causes included:

CC 1: The pyrophoric nature of the material was not fully recognized or treated accordingly, increasing risks related to storage, movement, and surveillance.

CC2: The material was not appropriately packaged for long-term storage and was stored beyond its useful life.

CC3: Communication issues during facility transition and the subsequent integration period resulted in a lack of complete awareness and assessment of hazards.

Gaps and Conditions

A number of factors led up to, and created the conditions for, the fire in Building 350. A series of events beginning in the mid-1960s and continuing through the incident in November 2017, resulted in conditions and gaps that predicated the fire. A number of these gaps and conditions, identified by the investigation team, are summarized in the following chart:

Gaps and Conditions
• The uranium material may have been mischaracterized and/or mislabeled when it was originally packaged. Further, the material was not packaged for long-term storage.

- The Hazard Analysis for the facility incorrectly screened out the pyrophoric nature of the material. In addition, other documentation specific to Building 350, including the Fire Hazard Analysis, pre-incident plan, and facility postings did not identify pyrophoric hazards. This occurred despite other reports or documentation that properly identified the pyrophoric nature of the material.
- Work planning and control processes were not executed effectively to identify and control all hazards. Subject matter experts appeared to be assigning controls outside of their areas of expertise. In addition, there was general reliance on an expert-based process without fully identifying and utilizing appropriate experts.
- Incomplete recognition of physical and chemical hazards. During transition of Building 350 to ANL, a comprehensive walk-through was not completed as a means toward fully understanding facility configuration, and fully identifying materials of concern, the status and condition of excess materials and associated packaging to be left in the facility after transition.
- Transition activities did not result in a full appreciation of existent conditions, vulnerabilities, and inventory concerns. There was a lack of appropriate assessments to identify the hazards associated with material configuration and material movements. Building 350 was never fully integrated into ANL processes and systems.
- The decision not to declare an operational emergency and reluctance on the part of laboratory and Federal staff to make appropriate notifications contributed to a less than adequate and, at times, ad hoc approach to initial response efforts, particularly as it related to effective communication.
- The Fire Department was not fully consulted or integrated into decision-making related to re-entry and recovery operations.
- Roles and responsibilities between ANL, the Argonne Site Office, and the NBL Program Office related to the management and oversight of Building 350, were not clear or were misunderstood.

Conclusions

Based on interviews, a review of relevant documents, and subsequent analysis, a number of conclusions were derived by the investigation team. The following is a high-level summary of specific identified strengths and weaknesses.

Strengths
• The Argonne Fire Department performed its duties in a professional manner, preventing the fire from spreading and potentially becoming more severe. Additionally, the Fire Department's performance in recovery efforts was notable and conducted beyond the scope of normal firefighting activities.
• Recent de-inventory efforts in Building 350 significantly reduced risk. By dispositioning more than 5,500 items in the last 3 years, the Curie content of the facility was reduced by 98 percent. Additionally, a significant amount of radioactive waste was removed from Building 350 in this timeframe.
• During the course of the investigation, laboratory and Federal personnel were candid, open, and willing to apply lessons learned from this incident. In addition, immediately after the incident, ANL initiated a series of steps to mitigate risk and develop a corrective action plan.

Weaknesses
• There was incomplete knowledge of the materials in the facility, their configuration, and the associated hazards. Consequently project personnel did not adequately consider the flammability and reactive properties of Building 350 materials.
• There was an absence or incomplete application of standards for storing, co-mingling, moving and surveilling materials. Further, procedures lacked necessary involvement of subject matter experts in work planning and controls.
• Informal and inadequate communication complicated pre-incident operations, incident awareness, and post-incident recovery actions.
• The emergency management processes available in the site emergency management plan were not fully utilized, which would have helped post-incident and recovery operations.
• Office of Science Headquarters program managers and acquisition executives did not fully appreciate the urgency of the de-inventory process and subsequently failed to articulate or advocate for sufficient funding in the Federal budget process.

The issues identified during the course of this investigation provide valuable lessons learned that should be considered by ANL and Federal management as they develop and implement a corrective action plan related to this incident. Further, specific conclusions and lessons learned pertaining to the handling and storage of hazardous materials, particularly pyrophoric materials, should be considered and applied, as necessary, across the Office of Science laboratory complex. As such, to help improve emergency response efforts and aid in the mitigation of future risk associated with materials located in Building 350, the Investigation Team recommends that ANL:

1. Review current storage configurations to ensure that there are no compatibility or combustible issues.

2. In cooperation with the Argonne Site Office, complete a full hazards analysis of the materials in the facility and conduct a skills gap analysis related to those materials.

3. Develop standards for storage strategy, packaging, material moves, surveillances, and involvement of subject matter experts in work planning and controls.

4. In cooperation with Office of Science senior management, jointly develop a management plan for Building 350 that assures integration of roles and responsibilities, communication strategies, and operational objectives. For example, establish an Integrated Project Team with senior officials from ANL, Argonne Site Office, and NBL Program Office to facilitate enhanced integration and communication.

5. Expand the current Extent of Condition analysis to include all pyrophorics and reactives in all buildings within the laboratory's purview.

6. Develop a mechanism to utilize current emergency management procedures without a declared emergency. Fully implement DOE Order 151.1D.

7. Develop and document a plan for recovery operations that identifies appropriately trained and equipped personnel to safely conduct recovery activities and the methods for their engagement and incorporation in the recovery process for an abnormal condition.

Additionally, the Office of Science should:

8. Prioritize funding for de-inventory and decontamination efforts at Building 350.

1.0 INTRODUCTION

On Monday, November 27, 2017, a fire began in samples of natural uranium metal located in a storage vault in Building 350 at ANL. Smoke detectors activated, the Argonne Fire Department extinguished the fire, and no injuries or worker contamination occurred during the fire response actions.

All radiological contamination surveys and air sampling showed that radioactive airborne contamination generated during the fire was contained within the immediate affected room and in the HEPA filtered system and did not affect any outside or surrounding facilities.

The materials involved in the fire were consolidated and repackaged, and will be disposed of according to standard Department procedures.

1.1. Argonne National Laboratory

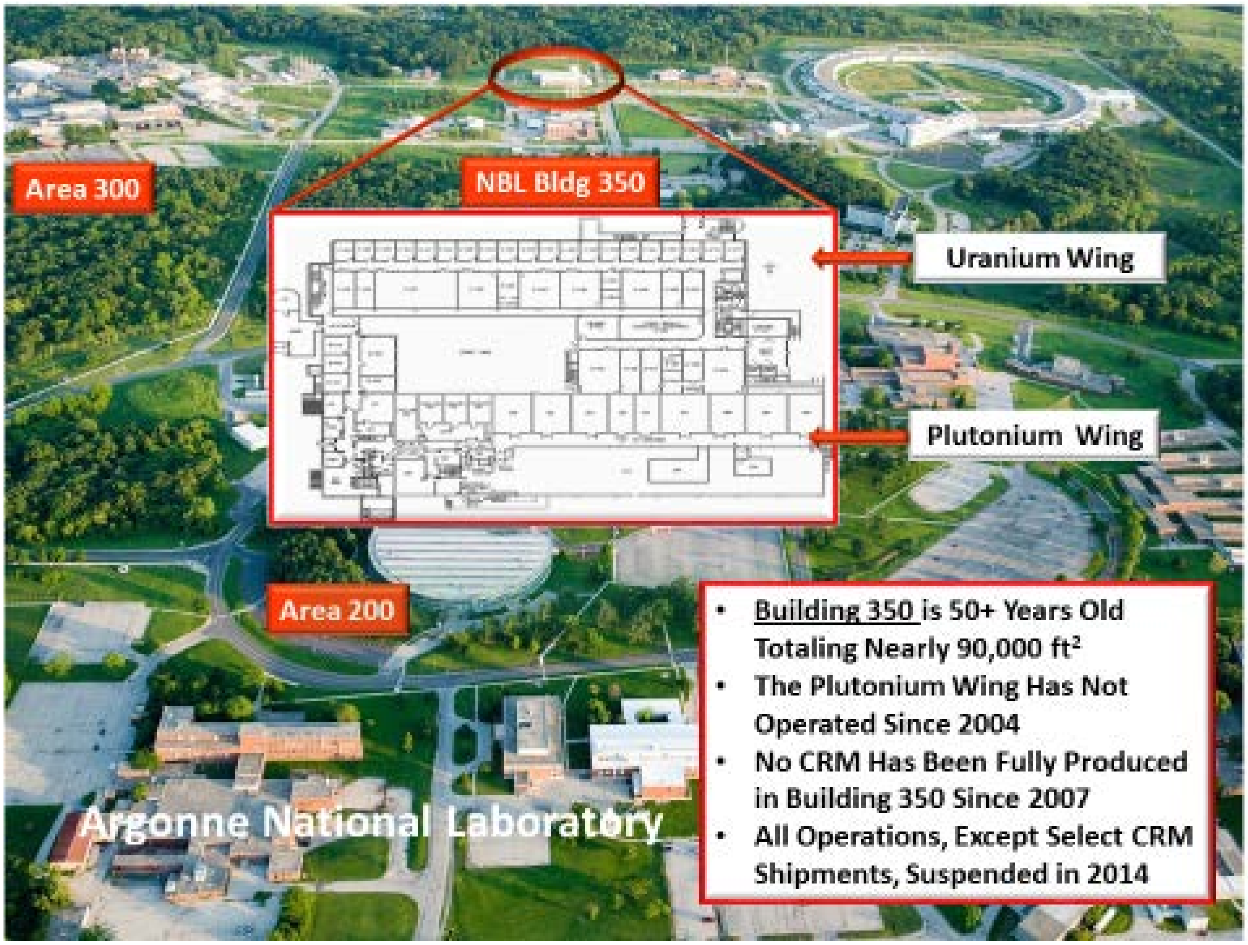
Argonne National Laboratory traces its origins to the Manhattan Project and the effort to create the world's first self-sustaining nuclear reaction. Beginning with the construction of Chicago Pile-1, criticality was achieved on December 2, 1942, underneath the University of Chicago's football field stands. The experiments were deemed too dangerous to conduct in a major city and, therefore, operations were moved to nearby Palos Hills and renamed "Argonne" after the surrounding forest. On July 1, 1946, the laboratory was formally chartered as Argonne National Laboratory to conduct "cooperative research in nucleonics." At the request of the U.S. Atomic Energy Commission, it began developing nuclear reactors for the nation's peaceful nuclear energy program.

Today, with an annual operating budget of more than $750 million and a workforce of approximately 3,200 employees, ANL is a multidisciplinary science and engineering research center. ANL executes a diverse research agenda with experimental, theoretical, and applied work in a wide range of areas, including nuclear energy, X-ray technology, physics, materials science, chemistry, biology, nanoscience, transportation, national security, mathematics, and high performance computing. This work takes place in more than 2 dozen research divisions and specialized centers at the laboratory and in ANL's 5 national user facilities, which drew approximately 8,300 users in Fiscal Year 2017. These user facilities include the Advanced Photon Source, Argonne Leadership Computing Facility, Argonne Tandem Linac Accelerator System, Center for Nanoscale Materials, and Atmospheric Radiation Measurement Climate Research Facility – Southern Great Plains Site.

1.2. New Brunswick Laboratory

The New Brunswick Laboratory was established by the Atomic Energy Commission in 1949 in New Brunswick, New Jersey. It was initially staffed by scientists from the National Bureau of Standards that had contributed to the measurement science of nuclear materials for the Manhattan Project. NBL's initial mission was to provide a Federal capability for the assay of uranium-containing materials for the nation's developing atomic energy program. Over the years, NBL expanded its capabilities, developing improved methods and procedures, and certifying additional reference materials for use around the world. The capability for plutonium measurements was implemented at NBL in 1959.

NBL was relocated from New Jersey to the site at ANL during the period 1975-77. Over the years, NBL maintained a Center of Excellence in analytical chemistry and the measurement science of nuclear materials. In this role, NBL performed state-of-the-art measurements of the elemental and isotopic compositions for a wide range of nuclear materials.



1.3. New Brunswick Laboratory Reorganization and Transfer

In May of 2016, NBL underwent a reorganization to adopt a new business model that allowed the facility to continue its mission to produce, sell, and deliver CRMs in a more efficient, effective, and sustainable manner. The reorganization separated NBL into two Federal organizations, a program office and a facility transition office. The NBL Program Office was tasked with fulfilling NBL's core missions to provide reliable, high-quality CRMs.

The Building 350 Transition Office was tasked with addressing long-standing legacy nuclear issues at Building 350. As such, the Transition Office worked in partnership with ANL to reduce the nuclear footprint, concentrating efforts on the de-inventory and decontamination of the former New Brunswick Laboratory location, prior to the facility being transitioned to ANL. The Building 350 Transition Office also assisted the NBL Program Office in distributing existing CRMs and ultimately relocating the NBL material inventory to appropriate future locations within the DOE complex. As a result of the de-inventory efforts in June 2016, Building 350 was downgraded from a Hazard Category Level-3 facility to a radiological facility. Subsequently, operational control of Building 350 was transferred to ANL in April 2017.

1.4. Purpose, Scope, and Objectives

Shortly after the incident, it was determined that an independent review should be conducted in order to determine the facts and circumstances related to the fire, as well as any necessary mitigation actions. Directed by the Office of Science Deputy Director for Science Programs, the charge was established on December 1, 2017. The investigation team was chartered to identify all relevant facts, determine the root causes of the incident, and develop conclusions and recommendations to prevent future occurrences. The team was further charged to evaluate the adequacy of the initial response to the event and to review both Federal and laboratory programs and oversight. The membership of the investigation team was selected to provide expertise in the necessary areas of review and to provide technical expertise in operational oversight, emergency response, and fire protection and engineering. Key elements of the investigative process were:

- Determining facts;
- Conducting a causal analysis;

- Interviewing Federal and laboratory staff;
- Evaluating work processes, relevant policies and procedures, and inspection criteria;
- Analyzing the laboratory's extent of condition analysis;
- Development of conclusions and recommendations; and
- Issuance of a final investigation report.

Based on the preliminary facts outlined in the immediate aftermath of the incident and the specific actions directed by the charge letter, the following scope areas were identified:

- **Scope Area 1:** Review the material history of the uranium metal shot located in Building 350 on the ANL campus. Determine when the material was produced and sent to NBL at Argonne. Since arriving at ANL, determine whether the material had been repackaged or moved. Provide a description of the incident as well as a detailed timeline of events.
- **Scope Area 2:** Evaluate the fact finding summary produced by ANL in the immediate aftermath of the fire. Engage directly with ANL staff to gain greater context and institutional insight in order to develop a causal analysis. Review and evaluate ANL's incident response, including emergency response procedures and actions, fire response efforts, and immediate remediation activities. Evaluate the effectiveness of current emergency response protocol models with recommendations for improvement for specific processes, programs, and communications.
- **Scope Area 3:** Evaluate facility and material requirements as well as relevant inspection protocols. Determine whether requirements and/or best practices were adhered to in terms of material packaging, storage, and surveillance. Further assess the transition from a federally managed facility to ANL in order to determine identified risks and acceptance criteria.
- **Scope Area 4:** Review the extent of condition analysis conducted by ANL to aid in the identification of potential areas or materials at risk. Identify recommendations to mitigate such risk.

Based on the above scope areas, specific objectives were identified. These objectives (by scope area), are provided in the following table:

Investigation Objectives	
Scope Area	**Objectives**
Scope Area 1: Material History and Incident Background	Determine the material history of the uranium metal shot, from when it was originally packaged to where it is stored today. Outline the history of NBL, including transition to ANL.

	Review the de-inventory effort and prioritization by the Building 350 Transition Office in preparation for transfer of the facility to ANL. Provide a summary of the incident, including a detailed timeline of events.
Scope Area 2: Causal Analysis and Incident Response	Evaluate the fact finding review conducted by ANL immediately after the incident. Develop a causal analysis. Evaluate ANL's immediate response to the fire, including the emergency response plan and actions taken. Evaluate the rigor and effectiveness of emergency response protocols/actions. Recommend improvements to emergency response protocols and procedures. Evaluate the laboratory's remediation actions and contamination testing regimen.
Scope Area 3: Requirements and Inspection Protocols	Assess the storage requirements for the combusted material and, specifically, whether these requirements were satisfactory. Assess the procedures for and actions taken to conduct, document, and evaluate the adequacy of surveillances throughout the storage period. Review the relevant inspection criteria and specific inspection history for the combustible material. Further, examine whether the storage configuration allowed for non-destructive examination. Evaluate material labeling and documentation as well as facility and room designations for radioactive and/or pyrophoric materials. Analyze cognizant hazard analysis documentation. Evaluate the protocols and actions related to material moves, particularly as it relates to radioactive and/or pyrophoric materials. Evaluate the process and acceptance criteria for transition of Building 350 to ANL. Identify initiatives to improve inspection criteria, adherence to storage requirements, or enhanced requirements in this regard.
Scope Area 4: Extent of Condition Analysis	Review the extent of condition evaluation conducted by ANL to determine whether similar circumstances may be present in Building 350 or other parts of NBL.

	Identify potential areas of future risk. Identify recommendations to mitigate current and future risk and/or improve current protocols and procedures.

Utilizing a number of documents and information gathered through interviews, the Investigation Team analyzed the relevant data to identify direct and contributing causes as well as develop conclusions and recommendations. The results of this analysis are outlined in the remainder of the report.

2.0 EVENT DESCRIPTION

On November 27, 2017, a fire began in samples of natural uranium metal located in a storage vault in Building 350 at ANL. At 12:08 a.m., the Argonne Fire Department was dispatched after a smoke alarm was set off in Room C-068A. After arriving on the scene, firefighters were alerted to a second smoke alarm in Room C-068 at 12:28 a.m. Room C-068 is adjacent to the room of the first alarm. At 12:30 a.m., after noticing a placard indicating a radiological hazard, firefighters entered Room C-068 and reported a light smoky haze.

Upon opening the vaulted door to Room C-068A, firefighters observed heavy smoke. After quickly shutting the door and notifying the Incident Commander, the firefighters re-entered the room. Utilizing a thermal imaging camera to see amidst the heavy smoke, flames of approximately two feet were seen coming from the top and left side of a storage cabinet across the room. After an unsuccessful attempt to use an ABC-type fire extinguisher to knock down the flames, a Class D extinguisher located in the room was used to put out the flames. The firefighters then layered Lith-X, a dry powder extinguishing agent, over the top of the fire location 3 times, in 10 minute increments.

Left: Material on Shelf 2 after fire, covered in Lith-X, before cleanup. Right: Shelf 2 after cleanup.

At 4:06 a.m., initial emergency responders left the event scene as the emergency situation was determined to be over. Once it was determined that the immediate emergency had been stabilized, a decision was made by ANL to move the remnants of the 48 containers of natural uranium that were involved in the fire. It was determined by ANL that the Argonne Fire Department was best suited for this task. After a second 9-1-1 call was placed, at 3:53 p.m., equipped with PPE and SCBA, firefighters re-entered the affected area. The pile of burned material was slowly scraped off the cabinet shelf and placed in a 30-gallon container, surrounded by layers of Lith-X. Once the remnants of the uranium material were put in the container, a 48-hour fire watch was initiated, with temperature recordings initially taken every 30 minutes.

The following day, Tuesday, November 28, a work plan and Radiological Work Permit were approved to retrieve four samples of similar uranium material located in an adjacent room. The four samples were placed in pint sized cans lined with Lith-X. The cans were then added to the 30-gallon container with the previously inserted burned material. Over the course of the next several days, ANL commenced a number of actions in response to the incident, including the development of a risk evaluation for the entire facility, cost estimates for recovery and disposition operations, and initial plans related to an extent of condition analysis. A more detailed description and analysis of the incident and the recovery actions is provided in Section 4.1.

Left: Affected cabinet after fire, before cleanup. Right: After cleanup, 30-gallon drum containing remnants of burned material.

2.1. Sequence of Events and Recovery Activities

Following the incident, on November 29, 2017, ANL convened a group to develop a timeline of events and response activities. The following is an account, provided by ANL, of that timeline.

Date	Time	Who	Information received from meeting
Monday, 11/27/17	12:08a	Argonne Fire Department	Received an activated fire/smoke alarm notification for Building 350 Room C-068A
Monday, 11/27/17	12:10a	Argonne Fire Department	Arrived on the scene – Building 350. Drove around the perimeter of the building. Bells and strobes could be heard and seen.
Monday, 11/27/17	12:13a – 12:19a	Argonne Fire Department	Contacted Security
Monday, 11/27/17	12:15a	Argonne Fire Department Responders	Report to the commander car located on the west side of Building 350 for instructions

Date	Time	Who	Information received from meeting
Monday, 11/27/17	12:26a	Argonne Fire Department	Cleared Security to leave the area
Monday, 11/27/17	12:28a	Argonne Fire Department	Received a second alarm for Building 350 Room C-068
Monday, 11/27/17	~12:28a	Argonne Fire Department Responders	In SCBA, evaluated the area using various tools (e.g., thermal imaging camera and heat gun); Noted extensive floor to ceiling smoke in the room.
Monday, 11/27/17	~12:30a	Waste Management, Building 350 Building Manager, Additional emergency personnel	Contacted due to the fire in Building 350
Monday, 11/27/17	12:35a	Argonne Fire Department Responders	Alerted Incident commander of extensive smoke and fire in Room C-068A • Temperatures of 600ºF were detected • An ABC Dry Chemical Fire Extinguisher was used to extinguish the fire, but it did not work • All of the contents of a Class D Lith-x Fire Extinguisher was used to successfully put the fire out (in total three layers of Lith-x was applied due to excessive heat)
Monday, 11/27/17	12:55a	Argonne Fire Department	Contacted Security Management and Emergency Management
Monday, 11/27/17	12:56a	On-call HP Technician	Contacted HP Operations Manager
Monday, 11/27/17	1:00a	Building Manager	Contacted Waste Management
Monday, 11/27/17	1:15a	Building Manager	Arrived
Monday, 11/27/17	1:30a	Building Manager	Contacted the MBA Custodian
Monday, 11/27/17	1:30a	Health Physics	Arrived and Surveyed AFD that were in the room – results were clean. Continued to monitor the room for excessive temperatures (inside and outside the room).
Monday, 11/27/17	1:31a	HP Operations Manager	RSO was notified
Monday, 11/27/17	1:40a	Waste Management	Arrived onsite
Monday, 11/27/17	~2:05a	Argonne Fire Department Responders	Temperature of 300º F were detected
Monday, 11/27/17	2:06a	Argonne Fire Department Responders	Was taken off supplied air and surveyed – all clean
Monday, 11/27/17	2:18a	Radiological Safety Officer	HSE Division Director was notified via email

Date	Time	Who	Information received from meeting
Monday, 11/27/17	2:24a	Director, Security & Emergency Services	CEPA, IS Division Director, COO Office received email notification after determination by Director and Emergency Management Officer determined the event was not an operational emergency.
Monday, 11/27/17	3:52a	Argonne Fire Department	Asked for Security to return to the building to search AFD responders
Monday, 11/27/17	4:06a	Argonne Fire Department	Mutual Aid returned
Monday, 11/27/17	4:30a – 5:30a	Health Physics	Conducted High Volume Air Monitoring for radioactivity in Room C-068A – results were clean
Monday, 11/27/17	~5:20a	MBA Custodian	Arrived on scene with the inventory information
Monday, 11/27/17	5:30a	Argonne Fire Department	Temperature of 150^{o}F was detected
Monday, 11/27/17	5:41a	Environmental Protection	Heard about fire alarm from email by HP Operations Manager
Monday, 11/27/17	6:40a	Argonne Fire Department	Temperature of 140^{o}F was detected
Monday, 11/27/17	~7:00a	Project Manager	Contacted the Argonne Site Office
Monday, 11/27/17	7:12a	Environmental Protection	Received photos from HP Operations Manager
Monday, 11/27/17	8:00a	Argonne Fire Department and Health Physics	Temperatures were checked every 30 minutes beginning at 8:00 a.m.
Monday, 11/27/17	8:30a	TBD	HSE-IH received verbal notification
Monday, 11/27/17	9:00a	Environmental Protection	Interim Deputy Chief Operations Officer and the Interim Deputy Laboratory Director for Operations stopped by and indicated the fire was RAD related and that air samples would be need by Building 350.
Monday, 11/27/17	9:00a	Project Manager and team	Reviewed the inventory report
Monday, 11/27/17	9:00 – 10:00	Environmental Protection	Made arrangement to conduct environmental protection monitoring tasks
Monday, 11/27/17	10:00	Environmental Protection	Received wind direction and wind speed at the time of the fire from met tower data. Wind was from the southwest during the fire.
Monday, 11/27/17	9:45a – 10:50a	Environmental Protection	Perimeter high volume samples changed (Monday). These outside air monitors were running during the fire.
Monday, 11/27/17	~10:00a	NWM Cognizant Systems Engineer	Reviewed drawings and provided input on the buildings ventilation system
Monday, 11/27/17	~10:00a – 11:00a	Waste Management Manager, Building Manager, Project Team	Discussed using the AFD to move the material

Date	Time	Who	Information received from meeting
Monday, 11/27/17	10:08a	Environmental Protection	Sent out Environmental Protection task listing to members of Environmental Protection
Monday, 11/27/17	10:11	Environmental Protection	Low volume field samples Building 350 (North and South) were deployed. Planned sampling was as follows: • 4 hours 11/27 am • 8 hours 11/27 pm • 4 hour 11/28 am • 8 hour 11/28 pm
Monday, 11/27/17	2:30p	Environmental Protection	Attended fire briefing meeting
Monday, 11/27/17	3:00p	NWM Division Director, IS Division Direction and Security Division Director	Conducted a meeting to discuss safety issue of removing/moving material in question. - A 911 was called to move the material
Monday, 11/27/17	3:30p – 3:56p	Waste Management and Argonne Fire Department	Moved the material in question into a 30 gallon drum
Monday, 11/27/17	3:40p	Environmental Protection	Received the inventory of the cabinet
Monday, 11/27/17	3:43P	Environmental Protection	Asked which shelf was involved
Monday, 11/27/17	3:46p	Environmental Protection	Confirmed shelf #2 was involved
Monday, 11/27/17	4:50p	Argonne Fire Department	The incident was secured
Monday, 11/27/17	4:54p	Environmental Protection	Reportable quantity determination was sent to the Interim Deputy Laboratory Director for Operations. There was not a reportable quantity release.
Monday, 11/27/17	6:00p	Waste Management	Conducted fire watch. Temperature readings were taken every thirty minutes
Monday, 11/27/17	6:32p	Environmental Protection	Emailed Argonne management to update about reportable quality decision and possible DOE/ASO decision to notify outside parties anyway.
Monday, 11/27/17	6:46p	Health Physics	The duct work post-HEPA was surveyed – no contamination was found
Tuesday, 11/28/17	7:52a	Environmental Protection	Resident dose calculation done 0.0075 mrem 220 m North
Tuesday, 11/28/17	9:05 to 10:10a	Environmental Protection	Perimeter high volume air samplers were changed (Ran Monday through Tuesday)
Tuesday, 11/28/17	11:30a	Environmental Protection	First environmental monitoring results communicated
Tuesday, 11/28/17	11:45a	Environmental Protection	Perimeter dose calculation done 0.0323 mrem 400 m SSW
Tuesday, 11/28/17	3:00p – 4:00p	Waste Management Project Team	A WCD was written, approved and work executed to gain entry into Room C-067 to remove 4 glass vials of material from the same batch to the material in question .

Date	Time	Who	Information received from meeting
Wednesday, 11/29/17	9:10a – 10:15a	Environmental Protection	Perimeter high volume air samplers changed (Ran Tuesday through Wednesday
Wednesday, 11/29/17	9:15a	Health Physics	Room reading of 72.5ºF; Infrared reading of 75ºF
Wednesday, 11/29/17	1:11p	Waste Management	Concluded fire watch
Friday, 12/1/17	Probably 10:00a	Environmental Protection	Perimeter high volume air samplers will be changed (Ran Wednesday through Friday)

3.0 MATERIAL HISTORY AND FACILITY REQUIREMENTS

3.1. Material Description

The material involved in the fire was naturally occurring uranium metal (U238 ~99.3%/U235 ~0.7%). In total, there were 52 containers of this material stored in Building 350, 48 of which were involved in the fire, each containing approximately 500 grams (with a total weight of approximately 26 kg or 50 pounds). The material was labeled as uranium shot (Lot F2703), and was believed to be packaged in the mid-1960s at NBL in New Jersey. According to information compiled by the NBL Program Office, the material was transferred from the former laboratory in New Jersey to the new NBL site at Argonne in 1977. However, no specific records have been identified that indicate its production or usage prior to 1989. A May 1989 General Analytical Evaluation Program Final Report references the material, in which it was considered surplus from this program.

Prior to 2000, it is suspected that the glass bottles were stored on open shelving in Room C-067, but no records can corroborate the exact location. In 2000, the bottom of a glass container broke, creating a contamination event in Room C-067. Following this event, the bottles were stored in a plastic bin in Room C-067 until being moved in 2017. This material move is further discussed in Section 3.

During the course of the investigation, it was found that the material may have been mislabeled and/or mischaracterized as it appears to be in a more finely divided form (0.5 to 1.0 mm spherical particles) than typically found of shot. This is important because uranium's pyrophoric properties increase as the size of the particles decrease (i.e., the more finely divided the particles the more pyrophoric the material becomes).

Finally, the material was not packaged for long-term storage. According to documentation reviewed by the investigation team, the uranium was packaged in glass bottles with screw-top plastic lids under an inert gas cover. The inert gas atmosphere cannot be maintained for prolonged storage because the glass containers are not airtight. Further analysis of the material and the incident is more fully detailed in Section 4.0.

Uranium Shot Material from 2010 (500g each)

3.2. De-Inventory of Building 350

As noted in the introductory section, an extensive material inventory, hazard assessment, and subsequent de-inventory effort for Building 350 commenced in 2014. From a nuclear facility categorization perspective, that de-inventory reduced Building 350 to a less than Hazard Category Level-3 facility and reduced the Curie content of the material stored in the building by 98 percent, from 230 Ci to 4.29 Ci. For historical perspective, the facility was previously reduced from a Hazard Category Level-2 to a Hazard Category Level-3 facility in 2008.

The de-inventory focused on the disposition of plutonium and highly-enriched uranium, which from a safety and security perspective was appropriate as this material presented the highest risk. Further, while the facility maintained that inventory, operations were curtailed due to nuclear safety requirements. As with any project, the scope of the de-inventory effort was limited by available knowledge and resources.

Additionally, a significant amount of radioactive waste was packaged and removed from Building 350 during this period. Radioactive waste had accumulated over a number of years and was another indicator of a general lack of hazard awareness as well as an incomplete process to identify and implement necessary controls. In 2014, general radiological awareness and training of NBL management and staff was found to be inadequate, leading to a stand-down of operations.

While there was notable recent improvement in the material condition of Building 350 as well as better work control standards, the years of neglect as well as inadequate work controls and radiological standards, while operating as a government owned/government operated facility, were identified as contributing factors to the fire event.

3.3. Transition of Building 350 to Argonne National Laboratory

<u>*Transition Plan and Turnover Packages*</u>: In December 2016, a *Building 350 Transition Plan (*Revision 0), was co-signed by ANL and the Argonne Site Office, which established a target transfer date for Building 350 of April 3, 2017. The transition plan identified five turnover packages for key subject areas and each turnover package contained a summary of pre- and post-transition activities related to the subject area, a description of status, resource estimates, identification of milestones and commitments, critical issues, a list of applicable documents and procedures, and identification of key personnel and individuals. The turnover packages were originally issued with the *Building 350 Transition Plan* in December 2016 and updated on April 6, 2017 (Revision 1). Revision 1 updated completion dates for the turnover package deliverables. Two of the turnover packages were reviewed as part of the investigation, *Physical Space and Regulatory Compliance Turnover Package* (PSR&C) and *Nuclear Material Control and Accountability and Nuclear Inventory Management Turnover Package* (NMC&A). The NMC&A turnover package was thorough and identified the high-level actions necessary to satisfy material accountability requirements. The PSR&C package identified high-level actions associated with meeting worker safety requirements such as derived from the Occupational Safety and Health Administration (OSHA) and 10 CFR 851. However, no actions were identified regarding the understanding of hazards in the facility or the condition of the materials that were expected to remain after transition.

Prior to transition, walk-throughs of the facility were completed by ANL and the Building 350 Transition Office, which included the ANL waste management division, ANL and Transition Office material control and accountability divisions, ANL health physics division, and NBL staff. Walk-throughs focused on supporting the de-inventory of CRMs identified to be sent off-site for use, excess material (i.e. radiological and chemical) scheduled to be wasted or sent for reuse by other programs prior to transition, material accountability, or focused on regulatory compliance. The ANL Radioactive Inventory Custodian for Building 350 completed a 100 percent material accountability inventory, with NBL staff present, following material control and accountability requirements consistent with Departmental requirements. The Radioactive Inventory Custodian indicated that the material inventory process involved picking-up containers and ensuring that all material was accounted for, but it did not include an analysis of the storage configuration, material packaging, or condition of the material.

Further, the turnover and walk-through process did not place a priority on identifying materials of concern, the status and condition of excess materials and associated packaging, and understanding the risk profile for facility configuration. Without sufficient knowledge of the hazards in the building, the lack of a thorough walk-through left the ANL building management staff at a disadvantage after the transition as efforts continued to de-inventory and manage the facility.

<u>*Hazards Identification and Hazards Analyses*</u>: The *Building 350 Legacy Project Transition Turnover Progress Report,* Action 4.24, stipulated that ANL would revise the Building 350 Hazards Assessment Document (HAD). NWM-NSB-606, *Facility Hazard Categorization,* identifies the expectations for development of the HAD. Prior to transition, ANL safety basis analysts confirmed the status of the facility hazard categorization using the sum of fractions methodology outlined in DOE Standard (STD) 1027, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Report,* and NWM-NSB-606.

The ANL *Hazard Assessment Document* (NWM-567) describes the hazards for the uranium metal shot in Appendix A as follows: "Pyrophoric metals: Material is in oxide or non-pyrophoric forms and will not be processed or change form. U metal shot (C067) may oxidize, but not spontaneously ignite." ANL used the HAD developed under the stewardship of NBL, *Hazard Assessment Document for Building 350,* and did not perform its own hazards analysis or validate the hazards analysis prepared for the NBL-approved HAD. Authors of the NBL HAD noted that all materials were not visually observed in completing the review. Instead, the author relied on interviews with NBL personnel to fill the gaps. The safety analysts preparing the ANL HAD did not do a walk-through of the facility with appropriate subject matter experts and relied on the analysis completed by NBL. Additionally, a full review of the existing hazard analysis, or development of a new hazard analysis, was not identified as part of the scope outlined in the PSR&C turnover package. Validation of referenced safety analyses and full facility walk-downs, as a form of quality assurance, represent best practices and should have been fully executed prior to finalization of the ANL HAD.

The wall-to-wall review of Building 350 materials conducted and documented in the *New Brunswick Laboratory 2016 Nuclear Material Physical Inventory Plan*, dated February 2016, which was completed by NBL staff and provided to ANL staff during transition, specifically identified the uranium metal shot. The hazard was described as a release of finely divided uranium particles if a bottle was dropped or broken. However, the pyrophoric nature of the material was not addressed.

Separately, the uranium metal shot was included in the *List of Potential Storage Concerns in B350* generated in 2014 by the Office of Science's Senior Nuclear Safety Advisor as a result of a detailed assessment of the Building 350 inventory. The document states, "these items remain in the facility, be aware of potential handling concerns, Room C-067 store room downstairs, finely divided metal shot (U235 normal); pyrophoric, 15 kg, packed in 8 oz glass bottles, plastic caps, oxide formation causing expansion of metal."[1] As previously outlined in Section 3.1., the Senior Nuclear Safety Advisor also noted that there was an incident in 2000 in which one bottle broke. Although this document was provided to ANL by the Building 350 Transition team through multiple means, including email and posting on a SharePoint site, multiple people interviewed, including the safety analyst that developed the NBL HAD and the ANL Radioactive Inventory Custodian, indicated that they did not recall seeing this document prior to the fire event. Many documents were being transferred to ANL over a short period of time. Interviews conducted during the course of the investigation indicate that the document was not recognized or fully understood by all appropriate personnel. Although multiple forms of communicating information were established during facility transition, it appears that some important information did not reach intended recipients.

Of the four documents reviewed related to hazards analysis, two stated that the uranium shot was pyrophoric, while two separate documents stated that the uranium shot was not pyrophoric. These conflicting analyses for the same batch of material were not questioned, or ultimately resolved. In addition to the HAD, other examples of improper identification of hazards were discovered. ANL staff was not aware of all the conditions in the facility after transition. During interviews, health physicists indicated that when the facility was transferred to ANL, they were not made aware that some of the hoods in the facility were unfiltered and did not understand the postings used to designate specific hoods as unfiltered. After transition, staff discovered materials being improperly stored in hoods, but for a period of time, did not realize that the improper storage was compounded by the unfiltered hoods. In short, this material was improperly packaged and stored for the hazard.

Integration of Building 350 into ANL Processes and Systems: The turnover packages identified actions associated with integrating the building into ANL data systems. However, decisions made as part of the emergency response efforts suggest that Building 350 was not fully integrated into ANL data systems and additional compensatory measures where not taken. For example, Action 1.18 of the *Building 350 Legacy Project Transition Turnover Progress Report* required a complete upload of inventory information into CURIE, ANL's system for tracking radiological inventory. ANL's procedure for managing radioactive inventories, *Managing Radioactive Materials Inventories* (LMS-PROC-45), requires that all on-site buildings use CURIE to track locations and characteristics of radioactive inventory items (i.e. isotopes, gram and Curie quantities). However, rather than individually uploading the more than 18,000 items remaining in the Building 350 inventory into CURIE, ANL developed a plan to manage and

[1] "U235 Normal" is a common term indicating material with 0.7% U235, which is similar to that present in natural uranium.

track the inventory collectively, uploading a single summary entry, as allowed by LMS-PROC-45.

The plan called for the Building 350 inventory to be managed in a local excel-based logbook (i.e., Inventory Logbook). The inventory logbook detailed each remaining sample, including sample location. This Logbook was stored in a shared electronic ANL folder (Box File) with limited access controlled by the Radioactive Inventory Custodian. CURIE inventory adjustments would be made at least quarterly. At other ANL facilities, each item is individually entered and tracked. However, for Building 350, having the information roll-up to a single summary level entry complicated matters for the Fire Department when responding to the event, which was unable to see the individual sample inventory of the building, either through CURIE or the Inventory Logbook.

Oversight of Facility: The investigation team found ambiguities in roles and responsibilities for oversight of Building 350 as well as ownership of materials. The building inventory has been divided into two types of materials, Defined Use and Non-Defined Use. Defined Use material is that which is part of the CRM program. When interviewing staff from the NBL Program Office and Argonne Site Office, there was confusion about who was responsible for each type of material. NBL Program Office staff indicated they were responsible for programmatic actions related to Defined Use material, but not the storage, packaging, and surveillance of this material. The Argonne Site Office indicated it was responsible for both Defined Use and Non-Defined Use material, but only from the perspective of de-inventorying the building as opposed to managing the inventory and storage requirements. Further, although a Facility Representative is assigned to Building 350, Argonne Site Office staff provided conflicting answers as to who had oversight responsibility for the facility beyond the Site Manager.

Summary Analysis: There were multiple examples identified during the investigation that indicate that the Building 350 transition did not take into account certain hazards or vulnerabilities. The turnover packages were executed at a high level and did not identify or track all actions needed to fully perform the transition. The lower level action items were the responsibility of each organization and there was no independent verification of actions completed. Further, the investigation discovered issues related to the identification of hazards and development of the hazards analysis, which screened out the pyrophoric nature of the uranium metal shot despite it having been identified in multiple documents as pyrophoric. Additionally, Building 350 was not fully integrated into the ANL processes as evidenced by the response of the Fire Department and their inability to identify what materials were in the building through ANL's internal tracking system.

3.4. Material Movements

On September 13, 2017, ANL completed a transfer of the 48 containers of uranium shot from Room C-067 to a storage cabinet in Room C-068A. The driver for the movement of the material was to minimize potential radiation exposure that was causing an office near a building entrance to be posted as a Controlled Area that could not be occupied 100 percent of the time. Downposting this office space was determined to be necessary to attract additional resident organizations to help subsidize the costs for surveillance and maintenance activities in Building 350. The radioactivity in the 1st Floor, C Wing office originated from material located directly below it in Room C-067. It was decided that material contributing to increased dose rates in the office could be moved from Room C-067 to Room C-068A, which is a vault area. Materials that were relocated included the natural uranium shot involved in the fire event, natural uranium metal, thorium oxide, thorium nitrate, thorium metal, uranium and radium bearing ores, and natural uranium tetrafluoride. This material was moved and the dose rate in the office was measured. This was repeated multiple times until the dose rate in the affected office was below the threshold required for radiation posting.

A general work control document, *Transfer of Material and CRM Packaging of Material B350* (B350- 50795.1), was in place when the radioactive materials, including the 48 containers of uranium shot, were moved within Building 350. The scope of Task 1 in the work control document covers intra-building transfers of radiological materials. Although it appears to cover all materials in Building 350, there are no controls for chemical or physical hazards (beyond radiological) pertaining to the materials being moved in both the job hazard analysis and work instructions section. In addition, the chemical compatibility of stored items was not addressed. The hazard analysis primarily lists controls for radioactive and standard industrial hazards such as ladder use and ergonomics. The work instructions mention limiting the amount of combustible materials brought into rooms where radioactive materials are being handled and packaged, but this does not flow from the hazard analysis. The only specific subject matter expert listed on the approval page was Health Physics. An Environment, Safety, and Health (ES&H) coordinator is also listed, but it does not appear that any other experts such as industrial hygienists, fire protection engineers, or actinide chemists were consulted in the development of this work control document.

Summary Analysis: There appears to have been incomplete involvement of subject matter experts to identify chemical, reactive, and pyrophoric hazards/controls in the development of the Building 350 work plan regarding material movement and storage. A lack of understanding regarding the chemical/physical hazards of materials by personnel assigned to the building may also exist which, in turn, can lead to a lack of a questioning attitude that is essential for a learning organization. A natural question related to the fire event is whether the recent movement of the uranium material contributed to its spontaneous combustion. Ultimately, it is difficult to ascertain whether this was the case. However, with that said, the pyrophoric nature of the material and the risks associated with the movement of the material was not a factor in the ultimate decision to relocate the material to the cabinet in Room C-068A.

3.5. Requirements, Protocols, Surveillances, and Other Documentation

Chemical Hygiene Plan: The latest revision of ANL's Chemical Hygiene Plan occurred on August 1, 2017. Section 5.3.1 states that ANL will provide subject matter experts, validated by its Health, Environment, and Safety Division, to identify chemicals that have the characteristics of a particularly hazardous substance. Section 5.3.2 further outlines the rigor employed in work control documents when a particularly hazardous substance is involved. In effect, Building 350 management and staff have the direct means to consult with laboratory subject matter experts about the chemical hazards and proper controls for the materials under their purview.

Hazard Communication: *Hazard for Chemicals* (LMS-PROC-288 rev.1), establishes the "process for communicating to Argonne personnel the identity of, and the hazards associated with, the hazardous chemicals to which they are exposed when working and what protection methods are available." Additionally, the ANL Chemical Hygiene Plan states that "information and training prescribed in 29 CFR 1910.1450(f) is provided to personnel engaged in laboratory use of hazardous chemicals as follows: Argonne personnel (excluding facility users and subcontractors) complete training as described in *Mandatory Training* (LMS-PROC-16), which includes *Laboratory Safety Training* (ESH115). This specific training is provided upon initial assignment and when exposure potential changes. The refresher training interval is three years or less. In addition, workers receive job-specific information from their organizations.

<u>Work Planning and Control</u>: Site-level procedures sufficiently address the integrated safety management process which involves defining scope, identifying hazards, implementing controls, performing work, and providing feedback. However, a breakdown appears to have occurred in properly identifying, and subsequently controlling, hazards related to the scope of work for Building 350.

In terms of work control documentation, a primary issue centered on the fact that the pyrophoric hazard was not recognized or managed accordingly. Effective work planning requires a complete scope of work with sufficient detail to assign work steps and define associated hazards. If a material characteristic such as pyrophoricity is not realized as a part of the work scope definition, while the potential exists during the remainder of the process to realize the hazard and develop controls that can only occur if the right skills are utilized. The prevailing thought process at ANL appeared to be that Health Physics is associated with all things radiological and Industrial Hygiene is associated with all things chemical. It appears that the assumption had been that if those two disciplines were involved, all issues and hazards were covered. In matters of pyrophoric material, chemical reactivity, and chemical compatibility, additional expertise such as fire protection must be consulted to provide a more robust analysis and mitigate potential risk.

The Building 350 Legacy Project completed a *Hazard Analysis Report for the Building 350 Legacy Project* (JMLT-205-Q-T006) that discusses the expectations for handling pyrophoric materials. It does not appear that this report was used in any work planning and controls related to the uranium metal shot. Another aspect of work planning is identifying hazardous conditions that may result during the evolution work and determining beforehand, and documenting in the work steps, how to handle upset conditions. Common upset conditions such as spills, unknown reactions, fire, etc. should be addressed with more rigor.

A work planning and controls review was completed by the DOE Office of Enterprise Assessments (EA) during the Summer of 2017. Although the focus was not on radiological facilities, EA made similar observations to those outlined in this section related to ANL work planning and control processes. The work planning and control processes are available and well-defined, but there were shortcomings in the use, and limitations of, pre-defined hazard control sets. In addition, all hazards had not been identified and analyzed by appropriate subject matter experts.

<u>Storage Conditions</u>: During the course of the investigation, several concerns were noted in the storage conditions within the affected cabinet, which contained the uranium metal shot. For example:

- The material lacked permanent, meaningful labeling. Labeling for long-term storage should include material type, form, origin, age of material and hazards, if applicable. Contact information should be provided, if available. Another effective method of communication is to make a note in the material tracking system for each container with special hazards, including the labeling information listed above.

- The material did not appear to be packaged in containers for long-term storage. When containers and storage methods are not optimal, containers can degrade over time, which in turn, increases risk to personnel, the public, and the environment.

In addition to these concerns related to the uranium metal shot, several items on the *List of Potential Storage Concerns* raise similar or related concerns. The investigative team identified issues related to the compatibility of hazardous materials co-mingled in the affected cabinet. Incompatible materials appeared to be stored in close proximity. For example, the pyrophoric uranium shot was contained in a plastic bin and oxidizers such as thorium nitrate are stored in close proximity to combustible materials.

As outlined in *Chemical Safety Life Cycle* (LMS-PROC-312 Rev 1), potential incompatibilities should be considered during waste storage and disposal that would occur if they mixed. This can be accomplished by distance or by secondary containment. For example, the following incompatible chemicals should be stored separately:

- Acids and bases apart;
- Acids, bases, and oxidizers apart from flammables;
- Organic acids apart from strong mineral acids;
- Oxidizers and reducing agents away from combustible material;
- Pyrophorics away from air; and
- Combustibles away from pyrophoric materials.

Finally, according to *Entry Placards for Hazardous Areas* **(**LMS-PROC-329, Rev. 0), "facilities shall establish the process for developing and posting entry placards to alert emergency responders, lab personnel, and visitors to specific hazards, entry requirements, and contact information for all areas used for hazardous work or which contain hazards that could become uncontrolled in an emergency." In the physical location where the fire occurred, it was difficult to determine what was stored in the rooms and cabinet from outside the area.

Surveillances: The *Surveillance and Maintenance Plan for the Building 350* (JMLT-205-Q-T013) was implemented in March 2017. It defines roles and responsibilities and covers life safety systems, security protection systems, surveillance activities, and building structural inspections. It also provides surveillance and maintenance rounds sheets.

The plan states, "Surveillance, inspections and operational checks are performed to verify the adequacy and condition of facility systems, work areas, equipment, and items." Among the items to be inspected are the adequacy of postings. The plan calls for routine monitoring by Health Physics and semiannual ES&H inspections. The plan does not specifically mention inspection/surveillance of items located in radiological material storage areas or a periodic chemical inventory. Additionally, the round sheets do not cover these items. Based on information provided to the investigation team, the remaining storage items of concern did not appear to have a periodic inspection.

Summary Analysis: Several weaknesses were identified related to the generation of work planning and control documents. It appears that the hazard analysis was not thoroughly applied to all job steps. Subject matter experts appeared to be assigning controls outside their area of expertise and there was uncertainty related to points of contact for chemical reactivity hazards. Separately, improved communication was deemed to be necessary such that hands-on workers are more cognizant of the chemical hazards of materials. As previously noted, improved communication with regard to hazard postings and placards is needed as well. Finally, weaknesses were identified regarding storage strategies, both from a material compatibility standpoint and in the use of containers that were not intended for long-term storage. While the long-term packaging issue was a long-standing legacy issue from NBL, improved surveillance may be needed in the short-term related to the condition of the remaining list of storage concerns.

4.0. Incident Analysis

As summarized in Section 3.1., the ignition source for the fire was finely divided uranium metal shot packaged in 8 oz. glass bottles with plastic lids. The uranium metal shot appeared to have the appropriate surface-to-mass ratio to support a pyrophoric reaction if the material came into contact with oxygen. The metal shot had been originally packaged in the glass bottles with argon used to prevent a pyrophoric reaction. At the time of the fire, 48 glass bottles containing the material were stored in gray plastic bins with the bottles in both a vertical and horizontal orientation.

Photo of Uranium Shot Material in 2014

Pictures of the uranium shot taken in 2014 that were reviewed by the investigation team displayed evidence that some of the material was discolored, indicating that some reaction had occurred over time and that the argon gas used to inert the material was not maintained in the bottles. On September 9, 2017, the bins containing the material were moved from Room C-067 to C-068A. Although the fire occurred on November 27, 2017, as previously noted in Section 3.4., it is possible that moving the material helped contribute to the ignition. It is likely that the movement of the material shifted the shot, and that shifting exposed additional shot that had not yet oxidized to the no longer inert atmosphere. Another possibility is that the move could have disturbed one or more of the lids allowing more oxygen into the bottles.

Another factor that was considered was the possible development of uranium hydride on the material. Uranium hydride may be formed when uranium metal comes into contact with water, including atmospheric moisture. Uranium hydride can be pyrophoric, reacting very vigorously with atmospheric oxygen. As stated above, the 2014 pictures showed discolored uranium shot and some of that discoloration could have been hydride. If uranium hydride is formed, it can be powder-like or flaky, increasing its surface-to-mass ratio and, therefore, making it even more susceptible to a pyrophoric reaction if exposed to atmospheric oxygen.

Either through the normal pyrophoric nature of the uranium metal shot, the development of pyrophoric uranium hydride, or a combination of both, the material was exposed to atmospheric oxygen and reacted. Experience with burning natural uranium at other sites suggests a burning temperature on the order of 800°F can be assumed. This temperature is sufficiently high enough to ignite the ordinary combustibles in the cabinet including the lids of the bottles and the plastic storage bins. After one bottle began to combust, the heat generated would have been able to breach other bottles through pressurization or melting of the lids. The breaching of the other lids would have exposed the material to oxygen resulting in more uranium shot having a pyrophoric reaction. As interviews with the firefighters indicated, only approximately six of the bottles were still intact after the fire was suppressed. The smoke development and flames seen by the firefighters would have primarily been from the ordinary combustibles involved in the fire and not the uranium, as burning uranium does not produce much of either.

Another factor to consider is that the fire could have been much worse. For example, thorium nitrate was stored in the same cabinet, several shelves below the uranium shot. Thorium nitrate is an oxidizer and, if it had ignited, the fire could have been larger and involved more radiological materials in the cabinet. Additionally, thorium oxide was being stored on the shelf directly above the uranium shot. If the thorium oxide containers had been breached by the fire, the event would have had a much greater radiological contamination consequence. Due to the observed contents of the cabinet, it is evident that consideration of the compatibility of materials was not a primary focus or concern during the material move from Room C-067 to C-068A, as discussed in Section 3.4.

Summary Analysis: Since transition to ANL management in April 2017, multiple material movements occurred within the facility. Past DOE reviews had suggested limited movement of materials within this facility given the nature of the material involved. The involved material had been photographed as part of prior DOE reviews and identified as suspect material prior to transition. The imprecise definition of "shot" may have implied to some a less reactive configuration. Regardless, as previously discussed, the movement and relocation was based solely on radiological-related implications and it appears that no other potential incompatibilities or ramifications were considered. The pyrophoric potential of the material was not recognized and, therefore, the implications of time degradation of the container (i.e. stored unchecked for decades) was not considered.

4.1. Incident and Emergency Response

As previously summarized in Section 2.0, on November 27, 2017, at 12:08 a.m., the Argonne Fire Department received an alarm signal from a smoke detector in Room C-068A in Building 350. The Fire Department responded and arrived at the building approximately two minutes after receiving the alarm with a crew including a firefighter, Lieutenant, pump operator, two paramedics, and a Battalion Chief. The Battalion Chief's first action was to drive around the building to look for signs of fire and conduct an exterior assessment of the facility. No signs of fire were visible from the outside of the building, but he observed an activated fire alarm and audible bells. The Battalion Chief established an Incident Command Post (ICP) and the Lieutenant and his crew went to the facility to prepare for entry. The firefighters made entry into the building and proceeded to the service floor to Room C-068. The firefighters noticed a slight odor outside Room C-068, but did not notice any smoke when looking inside the room through the window. Before making entry into Room C-068, the firefighters performed a sweep around the perimeter of Rooms C-068, C-068A, and C-067 to ensure no smoke had made entry into the service floor mechanical areas. During this time, a second smoke detector in Room C-068 went into alarm and the firefighter entry team was notified of the activation. The firefighters observed that Room C-068 was marked by placarding on the door as a radiation area. The firefighters donned SCBA and made entry into Room C-068 at 12:28 a.m.

Once in the room, the firefighters were able to see a slight haze of grey smoke on the ceiling. The Lieutenant radioed a progress report to the Battalion Chief, then proceeded to open the vaulted door to enter Room C-068A and observed heavy grey/white smoke from ceiling to floor with extremely limited visibility. Initially, the firefighters did not observe any heat, but heard a "cracking" noise signifying an active fire. The firefighters immediately shut the door, notified the Battalion Chief, and made plans to re-enter using a thermal imaging camera. The firefighters were using the thermal imaging camera to look for heat signatures, but were not able to see any heat due to the thick smoke until they got closer to the impacted cabinet. Heavy smoke prevented visibility as the firefighters were unable to even see their feet. Closer to the cabinet, they were able to observe visible flames venting out of the cabinet. The firefighters then applied an ABC Dry Chemical Fire Extinguisher on the exterior of the effected cabinet with the doors closed and that was partially effective in suppressing the fire. The doors were then opened and more ABC extinguishing agent was applied, but it was not able to extinguish the metal fire. As a result, the firefighters used a Class D metal extinguisher and noted that the fire was essentially suppressed. Several minutes later, the firefighters observed that the material began burning through the Class D agent, so more agent was applied and the crew requested Lith-X extinguishing agent from the fire engine. Multiple layers of Lith-X had to be applied to reduce the smoldering and glow of the material. Once three layers of Lith-X were applied, the temperature of the material began to decrease. The Lieutenant contacted the Battalion Chief prior to each use of the extinguishing agent, providing an update on the progress. The Lieutenant noted that multiple bottles looked broken or impacted in the cabinet.

The firefighters remained in SCBA and continued to monitor the temperature of the material with the thermal imaging camera and did not exit further than a 5x5 foot area outside Room C-068 to avoid spreading any potential contamination. One air bottle change-out was required to remain in the area. The firefighters remained on air until Health Physics personnel could survey them for contamination upon egress. Upon arriving at the ICP, Health Physics personnel expressed concerns to the Battalion Chief, retrieved survey equipment from in the building, and subsequently reported to the egress point (with only gloves as Personal Protective Equipment) to provide surveys of the firefighters. No contamination was found on the firefighters and they doffed their SCBA gear at 2:06 a.m. After taking temperature readings, the Fire Department terminated the emergency incident and filed the appropriate reports. However, the Building Manager was not aware that the incident had been terminated and there was not a formal turnover that occurred between the Battalion Chief and the Building Manager.

Summary Analysis: In general, a timely and commendable response was conducted by the Fire Department. At the time of entry, the Fire Department lacked awareness of the hazards in Building 350. Given the nature of the inventory, the decision not to upload the full inventory into ANL systems, or provide a compensatory measure, was problematic, caused confusion, and increased risk to responding personnel. The lack of a formal transition from the Battalion Chief to the Building Manager for recovery was noted. Separately, local processes did not address *protocols for protection of Health Physics personnel in this type of situation, which is of particular concern given the unknowns at the time of the incident.*

4.2. Incident Command and Notifications

Upon receipt of alarm, the Fire Alarm Office sent out a text message using standard commercial cellular text services to a standing list of ANL personnel. The text message provided notification to the multiple support staff regarding the incident. After being notified by the text message, the Director of Security & Emergency Services coordinated with the Emergency Manager. They utilized pre-developed Emergency Action Levels to identify potential categorization concerns and determined that:

- The building did have an alarm;
- There was a health and safety risk to personnel; and
- Mutual aid was for backfill, not immediate response actions.

As a result, the incident was categorized as a non-operational emergency based on the information available. As such, specific emergency management procedures and processes were not required and, therefore were not applied, for engagement and activation in this incident. The Emergency Services Director notified ANL leadership through an email at 2:25 a.m. Federal Site Office officials were subsequently notified by email. The Argonne Site Office notified the Deputy Director for Field Operations in the Office of Science by email at approximately 7:20 a.m. and, subsequently, made notification to the Department of Energy Headquarters Watch Office. Following its standard notification process, among other notifications, the Watch Office informed the pre-designated line organization (SC) point-of-contact.

At the time of response, the Battalion Chief contacted the Building Manager by phone. The awakened Building Manager was made aware of the facts known at the time, but was unable to provide insights remotely (there may have been a misunderstanding of the specific room involved). Subsequent to the initial conversation, while traveling to the incident, the Building Manager contacted the Battalion Chief in order to provide information about the nature of materials in the vault room, in broad terms. Once the fire was extinguished, the Building Manager and the Battalion Chief discussed next steps. The Building Manager and the Battalion Chief agreed that the Fire Department would monitor the situation until the temperature reached ambient levels. In addition, the Building Manager requested additional information from staff on the material inventory for the affected rooms, which was separately maintained and, as noted in Section 3.3., not tracked in detail within primary ANL systems (i.e., CURIE). Keeping apprised of the situation, the Building Manager notified ANL management that the temperature of the burned debris was decreasing. Finally, after responding and being dismissed early in the incident, pro-force security personnel returned to assist in the egress process and conduct a standard search of exiting firefighters.

Summary Analysis: DOE Order 151.1D was approved on August 11, 2016, with required implementation by September 11, 2017, without coordination with Department of Energy Headquarters. The DOE Site Office approved implementation plan for DOE Order 151.1D allowed implementation to be phased at Argonne through June 2019 without the required

Headquarters engagement. The categorization process outlined in DOE Order 151.1D could have aided emergency response efforts, particularly as it relates to the classification of an operational emergency. A significant amount of uncertainty existed as the incident initially unfolded, including a lack of knowledge concerning the configuration of the affected room, the actual material involved, the extent of HEPA filtering, and the specific contents of the room. Given the decision not to declare an operational emergency, the site lacked a defined incident management process and did not draw upon established operational emergency processes available to it as allowed in existing site plans. The declaration of an operational emergency or application of more robust, graded internal processes would have enhanced communication and notification efforts.

4.3. Recovery Planning

As the immediate emergency subsided and additional individuals arrived at the ICP, discussions turned to recovery and cleanup efforts. As such, initial discussions involving, at times, 20 or more people were held in the Building 350 conference room and focused on whether to immediately dispose of the remnants from the fire or allow for additional time. The Waste Management Division expressed safety concerns related to the materials on the shelf. Specifically, concerns centered on the negative impacts of a secondary flare-up of the combusted material. Although an inventory sheet was not reviewed, the Nuclear and Waste Management Division wanted to get the material in the drum immediately and have it secured and neutralized as much as possible. Upon discussion and expression of some opposing views, the decision was made to immediately dispose of the material. The Nuclear and Waste Management Division Director noted that ANL staff are not trained or equipped to do work utilizing SCBA. In executing this decision, a formal recovery procedure was not used and a documented plan was not developed.

The decision for re-entry and recovery operations was communicated by ANL management to the Battalion Chief, including instructions that the Fire Department would perform this action. It was decided by ANL management that a 9-1-1 call would be made in order to have emergency services re-engage into “emergency mode.” The Fire Chief was notified by the Battalion Chief of the plan and expressed concerns that there were safety issues and that the action was out of the normal scope of firefighting duties. Noting that the incident had been stabilized, the Fire Department preferred to monitor the situation and take temperature readings until ambient temperature was reached. At that time, the Waste Management Division could then perform a recovery operation. Recovery is not a normal request for a fire department as they are only expected to perform emergency response and, as noted, it was believed by some that the immediate emergency was over after the fire was put out earlier in the day. However, during the course of the investigation, it was conveyed that ANL did not have other personnel with recent experience using SCBA and that, given the situation, time was not available to develop the proper work control documents. ANL management determined that the plan for re-entry and command by the Fire Department, with support by Waste Management, was necessary to mitigate the situation and moderate safety concerns expressed by ANL and Office of Science leadership. Subsequent to this decision, the Fire Department requested a work control package, but was told that it would not be possible as emergency response operations would need to be reinstated in order to quickly conduct cleanup activities. The investigation team considers this an improper use of the Fire Department as the recovery effort is not part of an emergency response and, therefore, not within the scope of normal firefighting responsibilities.

During an ANL recovery planning meeting, the Argonne Fire Department's Safety Officer requested the Safety Data Sheet on the material, but the data was not received prior to subsequent recovery efforts. Additionally, the Safety Officer raised questions about the burned material and expressed discomfort to proceeding without additional information. Separately, others in the meeting expressed concerns about the potential for re-ignition and, as a result, the need for an expedited recovery and cleanup effort. Although temperature readings were measured at approximately 80-85°F, which indicated a lowered risk of flare-up, there were questions as to whether all the affected material had combusted and whether a secondary combustion event was still a risk.

The Fire Department requested a Radiological Work Permit given that the current document did not address emergency situations such as a re-ignition. However, in multiple interviews during the course of the investigation, it was conveyed that there was a need to avoid additional paperwork to expedite the work activities due to imminent safety concerns. As such, although a recovery procedure is available, a re-entry plan was developed with verbal review and no additional documentation. The verbal briefing included the Building Manager, Nuclear and Waste Management Division, Health Physics and the Fire Department, covering identified zones, access control, mitigations, and safety issues. Reliance upon the Fire Department's training and protective gear may have negated consideration of additional dosimetry needs, such as ring dosimetry given the potential for extremity exposure in the recovery (i.e. hand shoveling). It was at this time that the Fire Department requested a larger drum for the burned material in order to reduce any spillage of material during the cleanup action. The larger drum was likely a major factor in mitigation of broader room contamination during the recovery.

Prior to initiating recovery efforts, a briefing by the Nuclear and Waste Management Division to the Fire Department reviewed the necessary actions for cleanup, smears, and air sampling system operations. Upon re-entry, firefighters placed a blanket on the floor to collect any additional materials and prevent spreading. The firefighters used a hand shovel to scoop the material from the shelf to the 30-gallon drum. The first scoop resulted in a cloud of black ash and material being thrown in the air. The firefighters proceeded slowly and cautiously. After placing the burned material in the drum and applying more Lith-X, firefighters conducted smears and turned off air monitoring equipment. Surveys of the firefighter's equipment were conducted at egress by Health Physics, who wore Tyvek suits for the surveys. Firefighter turnout gear and equipment was identified as contaminated and the Fire Department worked with Health Physics to go through a doffing process. After firefighters were declared clean, they were dismissed from the scene. After management discussion, the drum was moved to Room C-068 so that a 48-hour fire watch could be established. Subsequent entries into the room confirmed that Lith-X, as a dust, had been scattered throughout the room, but contamination was limited to the drum and adjacent floor areas.

During the recovery effort, Building 350 was not evacuated, the building entry doors were propped open and staff freely entered and departed, the floor above the incident was occupied, non-emergency personnel remained in the Building 350 conference room and basement landings.

Although a declared emergency (per the 9-1-1 call), only the immediate area of the recovery operation was managed or restricted.

Post event, a member of the Fire Department became concerned and filed a radiation exposure report. Another firefighter requested internal survey testing through the process of a bioassay. This was requested on December 22, 2017, but not approved until January 10, 2018. The results of the bioassay were not known at the time of this report.

Summary Analysis: Planning input and execution by the Fire Department during the recovery effort aided in avoiding potential re-ignition opportunities and the spread of contamination. The lack of a non-operational emergency incident process or protocol, combined with the pace set for recovery actions, contributed to less than full engagement during decision-making. The lack of institutional response capability (e.g. trained staff or contracted response resources) resulted in the necessity to utilize the Fire Department to execute recovery efforts since they were the only individuals with recent use of SCBA. However, it is also clear that concerns related to further combustion and/or contamination contributed to the pace of specific actions as well as decisions to forego typical work planning and control processes, and the desirability of a fast response by the Fire Department. Recovery planning could have been improved by greater upfront attention and implementation of emergency preparation, planning, and related training. This could include a plan for recovery operations that identified appropriately trained and equipped personnel to conduct activities during an abnormal condition; radiological response procedures and practical drills; and a pre-defined and institutionalized process for contamination testing.

4.4. Contamination Management and Analysis

ANL Health Physics personnel performed very thorough surveys of the incident area, including Room C-068A, adjoining laboratory Room C068, the downstream HEPA duct from the hood located in Room C-068, and the Building 350 roof. The results of these surveys indicated that no contamination left the immediate area of the event (Rooms C-068A and C-068) and no significant contamination was generated from the event and subsequent recovery packaging activities. Acceptable contamination levels are dependent upon the radionuclide involved and are noted in Table 1 below.[2] The affected areas were posted in accordance with values associated with natural uranium.

Radionuclide	**Removable**	**Total (Fixed + Removable)**
U-nat, U-235, U-238, and associated decay products	1,000	5,000
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	20	500
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	200	1,000
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	1,000	5,000

[2] Surface Contamination values 1 in dpm/100 cm2 from 10 CFR 835 Appendix D

Tritium and STCs	10,000	

Table 1: Acceptable Contamination Levels for Natural Uranium

Air sampling results during the activities, and the derived action calculations from them, indicate that proper respiratory PPE was assigned and worn for all activities. Smear results were reported for both alpha (α) and beta-gamma (β) activities. The values are reported in disintegrations per minute per 100 square cm (dpm/100 cm^2). Air surveys are reported in terms of derived air concentration (DAC) and DAC-hrs. DACs are calculated values based on the activity on the filter and volume of air flowed through the filter (i.e. dpm/m^3). DAC-hrs are used to calculate dose based on the time spent in the area and the protection factor of the respiratory protection. In general, if a person without respiratory protection is exposed to 2000 DAC for 1 hour it would translate to a 5 rem dose. DAC values help Health Physics personnel determine how to post an area and how to define suitable respiratory PPE with a proper protection factor (PF) for entry into these areas. The goal is to keep total DAC-hours with respiratory protection as low as reasonably achievable. Areas in which an individual may be exposed to 12 DAC-hrs in a week or if an individual may be exposed to 100 percent of DAC must be posted as an Airborne Radioactivity Area and may require respiratory protection to enter.

<u>Environmental Monitoring Outside Building 350 (November 27 – November 29)</u>: There were two low volume air samplers deployed around Building 350 (one north and one south). The samples were collected in varying intervals (<24 hours) from Monday, November 27 at 10:00 a.m. to Thursday, November 30 at 8:44 a.m. These samples were analyzed for gamma emitting radionuclides and gross alpha/beta activity. No elevated levels of activity were found.

There were also large volume air samples collected at the perimeter. There are 11 continuous air sampling stations. These air samplers were running during the fire. They were changed on Monday, November 27; Tuesday, November 28; and Wednesday, November 29 at around 10:00 a.m. each morning. The 11 air samples were combined and gamma analysis was performed each day over 4 – 5 days. No gamma results indicated elevated levels of activity. The 11 air samples were then separated and counted for gross α and β. None of these results showed elevated levels for α and β.

<u>Room C-068A Post Event Smear and Air Surveys (November 27 from 3:00 to 8:39 a.m.)</u>: In order to perform these surveys with as low as reasonably achievable risk of exposure, Health Physics personnel instructed firefighters on how and where to perform smear surveys. Health Physics personnel were not SCBA trained and this strategy provided the best option to remain as low as reasonably achievable since the extent of the contamination was unknown and SCBA offered the best protection factor. Smears were taken inside the cabinet door in the area where smoke damage was evident, shelf #2 where the event occurred, shelf #1 above the event, the floor directly in front of the cabinet, the floor halfway between the cabinet and room exit, and the floor at the room exit. No significant removable contamination was found. The highest values were found inside the cabinet door (82 dpm/100 cm^2 α and 213 dpm/100 cm^2 β). Although the results were not considered "official data," they provided a basis for levels of protection for subsequent entries.

Air sampling was conducted between 4:30 a.m. and 5:30 a.m. on the day of the incident. Initial counts taken at 9:50 a.m. indicated a DAC of 1.36 before applying a protection factor. This value dropped to 0.71 after counting again at 6:00 a.m. the following day. This drop is attributed to normal radon decay. The DAC-hrs after applying a protection factor was calculated to be 0.0 since personnel were wearing SCBA during initial entries.

Maximum Contamination Levels (dpm/100 cm^2)		Rm C068A	Cabinet	Rm C068	Hood	FP Equip. & Ext. PPE
Post Event	Alpha	32	82			
	Beta	86	213			
After Material Moved to Drum	Alpha	939	2820			430
	Beta	1580	4750			625
Prior to Adding Four Additional Containers to Drum	Alpha			223		
	Beta			457		
After Adding Additional Containers to Drum	Alpha			2300	455	
	Beta			5080	828	

Table 2: Samples taken after the fire. Table represents maximum contamination levels counted from smears.

Room C-068A After Material Involved in Event Placed in Drum (November 27 at 6:29 p.m.): Smears of the floor in front of the cabinet, halfway between the cabinet and room exit, and at the room exit were taken. There was a modest increase in α and β contamination levels for these areas after the activity with the highest values being in front of the cabinet (939 dpm/100 cm^2 α and 1580 dpm/100 cm^2 β). An increase in these values was expected due to small particle size of the extinguishing agents and the reacted material being poured up. Direct measurements of the shelf were the event occurred indicated 10600 dpm/100 cm^2 α and 7430 dpm/100 cm^2 β.

Smears were taken on external surfaces of respirators of the three firefighters and ranged from 77 to 430 dpm/100 cm^2 α and 67 to 625 dpm/100 cm^2 β. Smears on the inside of each of the firefighters' respirators, the hallway and buffer area after job completion, and whole body frisk of the firefighters after doffing indicated no contamination. Air sampling showed 0.0 DAC-hrs exposure for the firefighters. These values show that firefighters were very meticulous performing this task given the nature of the material being packaged.

Room C-068A Survey II After Material Involved in Event Placed in Drum (November 28 at 11:12 a.m.): Smears were taken on all seven cabinet shelves. Each shelf had removable contamination. The contamination ranged from 643 to 2820 dpm/100 cm^2 α and 1420 to 4750 dpm/100 cm^2 β. Direct measurements of the materials on the shelves were not remarkable. Floor smears were repeated and values had decreased from measurements made the previous day. Values ranged from 162 to 207 dpm/100 cm^2 α and 326 to 399 dpm/100 cm^2 β.

Room C-068 Before 4 Vials Containing Uranium Shot Moved from Room C-067 and Packaged (November 28 at 1:03 p.m.): Smears were taken at eight locations in the lab. Four floor smears that included the area where the drum holding the event material was relocated were taken. Other areas where smears were taken include the hood sill, table top, the push cart top, and the table with the uranium saw. Results from all areas (except the hood sill which appeared to be cleaner) were comparable. The removable contamination for these areas ranged from 116 to 223 dpm/100 cm^2 α and 235 to 457 dpm/100 cm^2 β.

Room C-067 After 4 Vials of Uranium Shot Transferred to Room C-068 (November 28 at 4:36 p.m.): All room smears came back clean with the highest measured removable α at 3.9 dpm/100 cm^2 and highest measured removable β at 10.3 dpm/100 cm^2.

Room C-068 Fume Hood Survey (November 29 at 9:25 a.m.): Nine smears were taken within the fume hood. The hood is posted as a contamination area and the results were not remarkable for such an area. The removable contamination for these areas ranged from 90 to 455 dpm/100 cm^2 α and 150 to 828 dpm/100 cm^2 β.

Post job surveys of buffer and clean areas, inside personnel respirator PPE, and whole body frisks indicated no contamination.

Room C-068 After 4 Vials Containing Uranium Shot Moved from Room C-067 and Packaged (November 30 at 2:59 p.m.): More room smears were taken after this activity was performed by Health Physics and Waste Management personnel. No appreciable increase in contamination from previously measured values was observed. Smears were taken on the upper, middle, and lower outside sections of the drum containing the packaged materials. The removable contamination for these areas ranged from 1470 to 2300 dpm/100 cm^2 α and 3410 to 5080 dpm/100 cm^2 β. Post job surveys of buffer and clean areas, inside personnel respirator PPE, and whole body frisks indicated no contamination.

Duct (Post HEPA) and Roof Smears (Taken November 27, 28, and 30): The roof was surveyed in twenty locations and four interior duct locations past the HEPA filter were surveyed/smeared. No contamination was found.

Summary Analysis: Given the nature of the event (i.e. uranium fires generally deposit contamination only in the immediate vicinity), the fact that the fire did not spread or adversely affect other materials in the cabinet, and the positive actions of the Fire Department, a radiological release did not occur. However, the lack of known building configuration (to include upfront recognition of direct venting hoods), material configuration, condition and location (to include incompatible material storage considerations), could have thwarted appropriate monitoring and sampling. Appreciable additional sampling was undertaken denoting lack of initial planned coverage.

4.5. Causal Analysis

Direct Cause: The direct cause (DC) of an accident is the immediate event or condition that caused the accident. In this case, the event that immediately caused the fire was determined to be:

DC: Finely divided natural uranium that is susceptible to a pyrophoric reaction was exposed to oxygen and/or moisture, potentially developed uranium hydride, resulting in ignition leading to combustion of the material.

Contributing Causes: Contributing causes (CC) are events or conditions that, collectively with other causes, increased the likelihood of an accident, but which individually did not cause the accident. Contributing causes are conditions or events that alone were not sufficient to cause the accident, but were necessary for it to occur. These conditions or events, if not mitigated, increase the probability of similar accidents in the future.

CC 1: The pyrophoric nature of the material was not fully recognized or treated accordingly, increasing risks related to storage, movement, and surveillance.

CC2: The material was not appropriately packaged for long-term storage and was stored beyond its useful life.

CC3: Communication issues during facility transition and the subsequent integration period resulted in a lack of complete awareness and assessment of hazards.

4.6. Key Gaps and Conditions

A number of factors led up to, and created the conditions for, the recent fire in Building 350. A series of events beginning in the mid-1960s and continuing through the incident in November 2017 resulted in conditions and gaps that predicated the fire. The items in this section are observations made during the course of the investigation. Many of these gaps have already been identified as lessons learned by ANL and corrective action plans are being developed. In some cases, they are being listed in this report to document the issue. These underlying gaps and conditions (GC) are as follows:

GC1: Hazard Analysis incorrectly screened out the pyrophoric nature of the material.

NWM-567, *Hazard Assessment Document for Building 350*, stated that “Material is in oxide or non-pyrophoric forms and will not be processed or change form. U metal shot (C067) may oxidize, but not spontaneously ignite.” In addition, other documentation specific to Building 350, including the Fire Hazard Analysis, pre-incident plan, and facility postings did not identify pyrophoric hazards. This is contrary to other documentation, including the *List of Potential Storage Concerns in B350* document, which stated that the material was pyrophoric and cautioned the movement of the material.

GC2: Work planning and control processes were not executed effectively to identify and control all hazards.

The work planning and control documents for the September 2017 move of the material did not identify the fire hazards of the material and, therefore, did not identify any controls for the movement of the material. Furthermore, when the material was moved it was placed in the same cabinet with incompatible materials such as combustible packaging material and oxidizers.

GC3: Reliance on an expert-based process without identifying and utilizing the appropriate experts.

As it pertained to pyrophoric materials, there was little or no involvement of the appropriate ANL subject matter experts during work planning and control processes. This was the case even after the fire when four other containers were identified and handled without any apparent input from appropriate subject matter experts. Subject matter experts knowledgeable in fire protection as well as chemical and physical properties of uranium and other materials are necessary to completely and accurately identify and address potential hazards.

GC4: Transition activities did not result in a full appreciation of existent conditions and inventory concerns.

During interviews with laboratory and Federal personnel, it was apparent that the pyrophoric nature of the uranium material was not well known or treated accordingly. For example, specific personnel were not aware of the *List of Potential Storage Concerns in B350* document until after the fire event.

GC5: Post-transition, Building 350 was not fully integrated into ANL systems, complicating emergency response efforts.

Building 350 inventory was not entered into the ANL CURIE system as discreet items, but rather, was combined as one summary value for purposes of determining hazard categorization. Discrete items, along with their locations in the building, were tracked in a separate excel based logbook that was only accessible by a limited number of Building 350 staff and, therefore, not readily available to the Fire Department.

GC6: Decision not to declare an operational emergency and reluctance of laboratory and Federal staff to make appropriate notifications contributed to a less than adequate and, at times, ad hoc approach to initial response efforts.

GC7: Lack of Fire Department input on decisions for re-entry and recovery operations.

Interviews indicated that the ANL Fire Chief was not involved in the initial decision to use Fire Department personnel for recovery operations. However, the Fire Chief's concern with this decision was communicated to management after the initial decision. As a result, recovery and cleanup decisions were made without full and open input by the Fire Department.

GC8: Staff are not experienced or equipped for SCBA usage for site recovery operations.

Interviews indicated that the decision to use Fire Department personnel in the recovery effort was made, in part, as a result of Fire Department personnel being the only employees with recent use of SCBA. This activity is not part of a normal firefighting operations and firefighters were not appropriately trained to conduct recovery operations.

GC9: Decision for expedited recovery effort was made without all applicable information, including the cabinet inventory.

While the material inventory was known to some personnel planning the recovery effort, interviews indicated that not all management involved with the decision to perform an expedited recovery were aware of the cabinet's inventory. Additionally, oxidizers were still present in the cabinet and the thorium oxide was still on the shelf above the remaining uranium shot when the recovery efforts were taking place. If there was a concern with re-ignition, it would have been prudent to first remove the oxidizers before moving the potential ignition source.

GC10: Blurred roles and responsibilities associated with the management and oversight of Building 350.

Roles and responsibilities associated with the management and oversight of Building 350 were ambiguous, as evidenced by interviews with ANL, Argonne Site Office, and NBL Program Office staff.

GC11: Lack of assessment associated with the material configuration and related hazards for Building 350.

Walk-throughs of the facility prior to transition did not focus on identification of physical or chemical hazards that would remain in the facility, leaving ANL staff unaware of some hazards and, therefore, unable to protect against such hazards.

GC12: DOE O 151.1D was not yet fully implemented and the site lacked clarity on how to manage a non-OE incident.

Upon categorization as a non-Operational Emergency, there was no effort to employ existing and trained processes that were defined in the site approved plans and would have been required (as part of the Emergency Operations System) under 151.1D. The application of the existing site processes developed for an Operational Emergency, or the Emergency Operations System expected of 151.1D, would have provided structure for support, situational awareness, command and control, and enhanced communication and notification actions.

5.0. Extent of Condition

On December 11, 2017, ANL produced an initial extent of condition plan associated with the fire in Building 350. With the exception of the fire remnants and four additional jars of uranium shot that were moved to the 30-gallon drum, no additional samples of the same material were identified in Building 350. Though the risk from the metal shot containers was realized, or partially realized, ANL's initial extent of condition analysis concluded that the absence of additional metal shot containers in the inventory indicate that additional events based on metal shot storage are unlikely. However, in reviewing the current inventory for Building 350, ANL identified 2,346 items as "metal" or that provide an indication that there is a reactivity concern (e.g. pyrophoric). Based on an initial risk analysis by technical experts, it was estimated that approximately 1,100 of these items contribute to elevated risk for long-term storage.

ANL's extent of condition review illustrates that there is additional risk in the Building 350 inventory. Subsequent to developing an initial analysis, ANL developed, and continues to further develop, plans to relocate materials of concern into safe storage configurations and compliant transportation packages. In this regard, as of December 22, 2017, ANL had completed the following actions associated with its initial extent of condition analysis:

- Reviewed all contents of the affected cabinet (#6) in Room C-068A to confirm no additional risk to the containers that may have been compromised during the fire event.
- Reviewed the contents of adjacent cabinets (#5 and #7) in C-068A to ensure that no containers or the cabinet structure had been compromised during the fire event.
- Completed a risk ranking of the Building 350 inventory, which, as noted above, resulted in the creation of a list of approximately 2,400 items of concern, 1,100 of which posed the greatest risk and will be dispositioned first after the recovery efforts are completed.
- Reviewed current de-inventory project practices including all work packages in use at Building 350.
- Engaged planning and readiness activities to recover Room C-068, C-068A and compliantly and safely packaged the contents of cabinet #6 in Room C-068A for waste disposal.

In addition to these completed actions, ANL continues to execute a series of on-going site-wide extent of condition activities. These actions include:

- Revise the Building 350 Extent of Condition Plan to capture additional actions for identified deficiencies, including radiological materials stored in rooms without high efficiency particulate air (HEPA) filters, pyrophoric materials stored in rooms with sprinklers, non-compatibles stored in cabinets together, and corrections for National Fire Protection Association fire hazard labels that do not accurately convey hazardous materials warnings (Expected Completion Date: January 17, 2018).
- Complete a site-wide review of uranium metals and compounds (e.g. actinides, thorium, plutonium, neptunium, americium, depleted normal and enriched). Develop a list of

owners from Local Area Network Material Accounting System (Expected Completion Date: February 28, 2018).

- Send an alert to actinide metal users explaining what occurred at Building 350 and request users take action to safely store or request disposition of materials in accordance with relevant SDS (Expected Completion Date: February 28, 2018).

- Review actinide metal user inventory. A technical team will review user inventory and support users by walking down materials and providing storage advice (Expected Completion Date: February 28, 2018).

6.0. Conclusions and Recommendations

As detailed in preceding sections, a number of concerns and areas for improvement were identified by the review team. Following the fire in Building 350, ANL management took immediate action to improve a number of identified weaknesses. However, based on interviews with Federal and laboratory staff, document reviews, and subsequent analyses, the review team reached the following conclusions:

- Despite aggressive hazard reduction efforts in recent years, there was incomplete knowledge of the materials in the facility, their configuration, and the associated hazards. Consequently, project personnel did not adequately consider the flammability and reactive properties of Building 350 materials.

- There was an absence or incomplete application of standards for storing, co-mingling, moving, and surveilling materials. Further, procedures lacked necessary involvement of subject matter experts in work planning and controls.

- Informal and inadequate communication complicated pre-incident operations, incident awareness, and post-incident recovery actions.

- The emergency management processes available in the site emergency management plan were not fully utilized.

- Office of Science Headquarters program managers and acquisition executives did not fully appreciate the urgency of the de-inventory process and subsequently failed to articulate or advocate for sufficient funding in the Federal budget process.

Based on these conclusions, to help improve emergency response efforts and aid in the mitigation of future risk associated with materials located in Building 350, the Investigation Team recommends that ANL:

1. Review current storage configurations to ensure that there are no compatibility or combustible issues;

2. In cooperation with the Argonne Site Office, complete a full hazards analysis of the materials in the facility and conduct a skills gap analysis related to those materials;

3. Develop standards for storage strategy, packaging, material moves, surveillances, and involvement of subject matter experts in work planning and controls.

4. In cooperation with Office of Science senior management, jointly develop a management plan for Building 350 that assures integration of roles and responsibilities, communication strategies, and operational objectives. For example, establish an Integrated Project Team with senior officials from ANL, Argonne Site Office, and NBL Program Office to facilitate enhanced integration and communication.

5. Expand the current Extent of Condition analysis to include all pyrophorics and reactives in all buildings within the laboratory's purview.

6. Develop a mechanism to utilize current emergency management procedures without a declared emergency.

7. Develop and document a plan for recovery operations that identifies appropriately trained and equipped personnel to safely conduct recovery activities and the methods for their engagement and incorporation in the recovery process for an abnormal condition.

Additionally, the Office of Science should:

8. Prioritize funding for de-inventory and decontamination efforts at Building 350.