Type B Accident Investigation of the August 5, 2003 Plutonium-238 Multiple Uptake Event at the Plutonium Facility, Los Alamos National Laboratory New Mexico

National Nuclear Security Administration

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On August 11, 2003, I appointed a Type B Accident Investigation Board to investigate the August 5, 2003 radiological event at TA-55 at Los Alamos National Laboratory, in Los Alamos, New Mexico. The Board's responsibilities have been completed with respect to this investigation. The analysis, identification of contributing and root causes, and judgments of need reached during the investigation were performed in accordance with DOE Order 225.1A, *Accident Investigations*.

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

Ralph E. Erickson
Manager, Los Alamos Site Office
National Nuclear Security Administration

November 4, 2003
Date

This report is an independent product of the Type B Accident Investigation Board appointed by Ralph E. Erickson, Manager of the Los Alamos Site Office of the National Nuclear Security Administration, U.S. Department of Energy.

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

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

This report neither determines nor implies liability.

Prologue

Interpretation of Significance

On August 5, 2003, a release of plutonium-238 occurred in a storage room at the Plutonium Facility, Los Alamos National Laboratory, resulting in radiation doses to two workers in the room. The Accident Investigation Board concluded that the direct cause of the accident was the release of airborne contamination from a degraded package that contained cellulose material and plutonium-238 residues. The package had been in storage in the room since 1996, and chemical, radiolytic, and thermal decomposition of the contents and the packaging materials had caused two inner boundaries to fail. Corrosion of the outer canister caused the "breathable" seams to seal, allowing decomposition gases to build up in the package. The simple handling of the package by one of the employees dislodged the corrosion at a junction between two seams in the outer canister, and the contaminated gases vented to the room atmosphere.

The Board concluded that this failure was similar to previously observed failures of plutonium packages in storage. The failure mechanisms had been recognized and evaluated by both the Department of Energy and the Defense Nuclear Facility Safety Board, and recommendations, guidance, corrective actions, and lessons learned had been widely disseminated almost two years before this package was created in 1996. Furthermore, since 1994 there had been multiple near misses and other precursor events concerning the storage of the same materials involved in this accident. However, there was no design for the packaging configuration, no analysis of compatibility between contents and packaging materials, and no control on what could be placed in the packages. There was no formal periodic surveillance of the packages, no schedule to process the residues, and no limit to the quantity of plutonium-238 that could be stored in the room. There was no hazard control plan in place for the room or the activities in the room.

After evaluating the conditions of this release and reviewing the available literature, the Board concluded that the consequences of this accident could have been much greater than they actually were. It was nothing more than the fortunate geometry and timing of the release that limited the consequences to the employees. Had the release point been facing directly towards one of the employees, or had the pressure increased further before it vented, the resulting doses could have been significantly higher, perhaps by orders of magnitude. There were no barriers in place to prevent such circumstances.

At the most basic level, the lesson to be learned from this accident is the importance of lessons learned. This accident could have been avoided simply by applying the knowledge that was already available when this package was created in 1996. The purpose of investigating our accidents is to learn from them. But to avoid an accident's recurrence we must do more than write down the lessons learned, we must internalize them and apply them in every operation at all of our facilities.

Ralph E. Erickson, Manager
Los Alamos Site Office

Executive Summary

On August 5, 2003 at 2:13 p.m., a continuous air monitor alarm actuated in room 201B in the Plutonium Processing and Handling Facility, Technical Area-55, at Los Alamos National Laboratory. Two workers in the room at the time of the alarm immediately evacuated to an adjacent room. Both workers had detectable levels of external contamination and their nasal smear results indicated potentially significant intakes of plutonium-238 (Pu-238). Initial dose estimates based on the nasal swipes suggested that the radiation doses could be in excess of 10 rem Committed Effective Dose Equivalent, which is twice the Department of Energy's annual limit for occupationally exposed workers. (The most recent estimates, based on bioassay results, now indicate that the doses are on the order of 2 to 3 rem.)

On August 11, 2003, Ralph Erickson, Manager, National Nuclear Security Administration, Los Alamos Site Office, ordered a Type B Accident Investigation to identify the cause of the accident and to identify lessons learned to prevent such accidents in the future.

The Accident

On August 5, 2003, two employees were conducting a pre-inventory check of accountable packages stored in room 201B. The packages contained residues from Pu-238 operations that were being stored while waiting further processing. The work required that the workers gain access to a shelving unit, referred to as a "cage," behind some portable radiation shielding and attached to the wall for seismic restraint. The employees would then remove individual packages in the cage and verify the packages' identification numbers against an inventory listing. Once the numbers were verified, the packages would be returned to their position in the cage.

During the progress of this pre-inventory check, the continuous air monitor alarmed unexpectedly, and the employees left the room immediately. The employees had not observed anything out of the ordinary before the alarm occurred, such as a visible defect on the exterior of the packages they were working with, nor did they drop or otherwise mishandle a package. After leaving the room the employees checked themselves for contamination, and upon finding some they summoned the responsible radiological control technician for assistance.

The Type B Accident Investigation Board (Board) concluded that the direct cause of the accident was the release of airborne contamination from a degraded package containing cellulose material and Pu-238 residues. The package had been in storage in the room since 1996, and chemical, radiolytic, and thermal decomposition of the contents and the packaging materials had resulted in significant corrosion and gas generation within the package. Each of these storage packages has three boundary layers, (1) an "inner can", (2) a polyvinyl chloride plastic bag, and then (3) an "outer can". The corrosion had caused the two inner packages to fail and release their contents into the outer package. The corrosion also caused the "breathable" seams of the outer package to seal, resulting in a buildup of gas pressure within the outer package. The simple handling of the package by one of the employees dislodged the corrosion at a junction between two seams in the outer can, and the contaminated gases vented to the room atmosphere. The Board concluded that the phenomena involved in the failure of the three boundaries were consistent with previous failures that had been observed during the storage of plutonium, and therefore this failure did not represent a unique or unexpected condition.

Results and Analysis

Los Alamos National Laboratory accepted the risk to the two workers involved in this accident without attempting to understand the magnitude of the consequences or the probability of the occurrence. The storage of Pu-238 residues in this room had been underway since late 1995, and many of the packages in the room dated back to that beginning. However, there was no design for the packaging configuration, there was no analysis of the interactions between the contents and the packaging materials, and there were no controls on the quantity or type of materials that could be placed in the packages. There was no formal inspection or surveillance program to periodically ensure the integrity of the packages, there was no schedule or plan to complete the processing of the materials, and there was no limit to the amount of packages or quantity of Pu-238 that could be stored in the room. There was no hazard control plan in place for the room or the activities conducted in the room.

As noted, the Board concluded that the failure mechanisms that had led to this release were known from previous plutonium storage package failures that had occurred both at Los Alamos National Laboratory and at other facilities in the weapons complex. These failures had been recognized and analyzed, and the resulting information had been widely disseminated by the Department of Energy and the Defense Nuclear Facility Safety Board as early as 1994. In fact, much of the work conducted in support of these studies, and much of the continuing effort to understand issues with the storage of plutonium, has been conducted within the same Directorate involved in this current accident. Concerns over the packaging of these materials has resulted in two Defense Nuclear Facility Safety Board Recommendations, with the first one in 1994. However, the Board believes that the Department's and Contractors' responses to these recommendations addressed the concerns as a legacy issue to be handled as a project and corrected as funding became available, and therefore the recommendations did not result in a fundamental change in the recognition of these unsafe packages as a worker safety issue.

Los Alamos National Laboratory has had multiple near misses since 1994 that should have improved their understanding and recognition of this type of accident. In 1994, cheesecloth used to clean a Pu-238 glovebox was stored in a can in the air glovebox overnight when it ignited from the embedded Pu-238. This was discovered the next day when a plastic bottle was found melted to the side of the can. During the evaluation of that event, concerns were raised about the similar material stored in the same room where this current event occurred. These packages were inspected, and one package was found with corrosion seeping out from under the lid and flowing down the outer surface of the package. When that package was put into an air glovebox and opened for evaluation, the cheesecloth ignited as with the first event. The reason for the corrosion was never determined. A Type C accident investigation was conducted to evaluate these two events, which concluded with six findings, four concerns, and six judgments of need. This Board reviewed the corrective actions taken after the Type C investigation, and found that in general they were either ineffective or inadequate to address the concerns identified. Furthermore, this Board concluded that, had those corrective actions been effective, this current accident might have never happened.

Since that time Los Alamos National Laboratory has observed multiple failures of individual boundaries of the three-layer package, but had not experienced a release from those failures. Other than to inspect a few other packages deemed similar to those that failed, there appears to have been no action taken to correct these conditions. In fact, the packaging system and practices in use today for the storage of Pu-238 residues have not changed substantially since 1995. After reviewing the information available on these events, the Board concluded that all of them had sufficient similarity to this accident that they should be considered as direct precursors to this current accident, and should have prompted changes in the operational practices.

The Board found that the current authorization basis for the facility, a Safety Analysis Report completed in 1996, had evaluated the storage of material in this room. However, the Board identified several weaknesses or deficiencies in that analysis. The authors of the 1996 Safety Analysis Report had concluded that any public and environmental consequences from an accident in the room would be enveloped by other accidents, and therefore the only control established was the seismic restraints for the cages. The analysis also concluded that the consequence to a worker in the room from accidentally dropping a package and having it fail would result in doses greater than the regulatory limits. However, this concern was never carried forward into establishing controls for the protection of workers in the room. The Board noted a contradiction in philosophy where the Safety Analysis Report assumed that these packages would fail within a few years, but the facility assumed either that the packages would maintain intact or that any failures would be inconsequential.

The Board reviewed the work controls that govern work in the facility, and the implementation of those controls. The Board concluded that the work controls were inadequate, and the implementation of those controls was ineffective. The Los Alamos National Laboratory relies heavily on the knowledge and experience of the individual worker and does not enforce a strict adherence to procedures and requirements. Even with a narrow focus on this accident, the Board found several instances of failure to adhere to procedures, inadequate procedures, and practices for which there were no procedures. The Board concluded that the conduct of operations was not effective in managing the activities being performed at the time of the accident. Furthermore, the Board concluded that the organizational safety culture has evolved to one of complacency towards safety such that workers and managers fail to respect the hazards present in the workplace, and risks to workers are accepted without understanding the magnitude of those risks.

Conclusion

The Board concluded that this accident was preventable. Furthermore, the Board is very concerned that the significance of this accident might be misunderstood or underestimated. After evaluating the conditions of this release and reviewing the available literature, the Board concluded that the consequences of this accident could have been much greater than they actually were. It was nothing more than the fortunate geometry and timing of the release that limited the consequences to the employees. Had the release point been facing directly towards one of the employees, or had the pressure increased further before it vented, the resulting doses could have been significantly higher, perhaps by orders of magnitude. There were no barriers in place to prevent such circumstances.

The Board found that the 1994 Type C investigation contained several recommendations that, if followed proactively, would have precluded the occurrence of this accident. But also of interest to this Board is the concluding remark of that 1994 investigation:

> *Following the first occurrence on October 12, 1994, it was a prudent action to begin a campaign to evaluate and process the waste cans. However, once started this campaign may have benefited from closer control of anomalous cans, improved communication, record keeping, observation and documentation. A formal review meeting or critique, if held, may have set the proper tone to promote this. This lack of formality may have carried over in the form of insufficient attention paid to measures that may have prevented the second occurrence. Once the fire was discovered (second incident), emergency response measures proceeded adequately, but fortuitous operator response may have minimized the consequences of the incident.*

In March 2000 a release of Pu-238 occurred in another of the rooms operated by the same group involved in this current accident. In that case, eight workers were exposed to the material, and three workers received radiation doses significantly in excess of the DOE regulatory limits. The Type A Board that investigated that accident made the following statement:

> *The accident investigation board concludes that this accident was preventable. Weaknesses in work planning and control, formality of operations, hazard analysis, design of auxiliary systems, and configuration control significantly weakened the barriers between the workers and the hazard. Los Alamos National Laboratory missed opportunities to correct the contributing causes and possibly to prevent this accident when they failed to adequately analyze and learn from previous related events. Contributing to the accident was the lack of balance between control of operations, workers' operational freedom, reliance on workers' knowledge in making operational decisions, communications between work groups, and barriers designed to prevent adverse events.*

As recently as one month before this most current accident, the DOE Office of Price-Anderson Enforcement wrote an Enforcement Letter to the Los Alamos National Laboratory. That letter stated, "The Office of Price-Anderson Enforcement is concerned that nuclear safety at the Los Alamos National Laboratory continues to demonstrate a negative performance trend. Our observations are based on numerous recent events involving both nuclear safety and radiological control issues."

Given these quotations, it is difficult to find new words to describe this current accident. The weaknesses observed in 1994 concerning the lack of formality and communication, the failure to document experiences, and the failure to learn from the previous events were clearly present in this current accident. The weaknesses observed in 2000 concerning work planning and control, formality of operations, hazard analysis, design of auxiliary systems, and configuration control were significant factors in this accident. The lack of balance between formal controls and worker knowledge and experience, and the reliance on workers' knowledge is still present today. Consequently, the negative performance trend observed by the Office of Price-Anderson Enforcement is reinforced by this accident.

This Type B Accident Investigation Board is very concerned about the implication of these observations. Los Alamos National Laboratory appears to have a great deal of difficulty in addressing worker safety issues, and to date has been unable to affect the lasting changes in the safety culture that are necessary to reverse the negative trends and improve the formality of operations. The Board concluded that two of the three root causes of this event were that (1) the Nuclear Materials Technology Division failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers; and (2) they failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group.

It is clear to the Board that the Department of Energy and the National Nuclear Security Administration have also struggled with their role as managers and overseers of this facility. The Board concluded that the Department of Energy, the National Nuclear Security Administration, and Los Alamos National Laboratory all had failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for these activities. The Board's intent in focusing this root cause on all parties is to acknowledge that all have a shared responsibility to ensure that adequate and appropriate efforts are always taken to understand the magnitude of the risks that we accept for the workers, and to ensure that all reasonable and appropriate measures are taken to manage that risk to an acceptable level.

It is unfortunate that we need to have an accident to learn these lessons, but often it is only because of an accident that we take a hard look at ourselves. We are fortunate that the consequences of this accident are not as damaging as they might have been, but we must not allow that to dilute the importance of the lessons.

Causal Factors and Judgments of Need

The judgments of need determined by the Board are presented in Table ES-1. The causal factors are identified in Section 3.12 of the report, but are also shown in Table ES-1 as the basis for the judgments of need. Judgments of need are managerial controls and safety measures the Board believes necessary to prevent or minimize the probability of a recurrence of this type of accident. Judgments of need are derived from the causal factors and are intended to assist managers in developing follow-up actions.

The **direct cause** is the immediate event or condition that caused the accident. The Board concluded that the direct cause of the accident was the release of airborne contamination from a degraded package that contained cellulose material and Pu-238 residues.

Contributing causes (CC) are events or conditions that collectively with other causes increase the likelihood of the accident but that individually did not cause the a accident. A summary of the Board's causal factors analysis is presented in Table 3-3 of Section 3.12.

Root causes (RC) are the events or conditions that, if corrected, would prevent recurrence of this and similar accidents. The root causes are derived from the contributing causes. The Board concluded that there were three root causes for this event:

RC1 The Nuclear Materials Technology Division failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers handling Pu-238.

RC2 The Department of Energy, the National Nuclear Security Administration, and Los Alamos National Laboratory failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group.

RC3 The Department of Energy, the National Nuclear Security Administration, and Los Alamos National Laboratory managed the Defense Nuclear Facility Safety Board's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers.

Table ES-1 Judgments of Need

No.	Judgment of Need	Related Causal Factors
JON 1	NMT needs to evaluate the Pu-238 operations and ensure that the residues and wastes are minimized, those generated are packaged with properly designed packages in accordance with DOE approved criteria, and a final deposition plan is developed and approved by LASO.	❑ The Nuclear Materials Technology Division (NMT) failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ DOE and NNSA failed to provide comprehensive and adequate requirements and guidance for the packaging and storage of Pu-238 bearing materials. (CC12)
JON 2	NMT needs to conduct a comprehensive hazard analysis for the packaging, handling, and storage of all Pu-238 bearing materials within TA-55, including that in-process and interim storage. The lessons learned from other plutonium packaging experiences in DOE need to be included in this hazard analysis.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1)

No.	Judgment of Need	Related Causal Factors
		❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)
JON 3	NMT needs to develop and implement controls to protect the workers and, if necessary, the public and the environment, from the hazards identified as a result of the analysis conducted for JON 2.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)

No.	Judgment of Need	Related Causal Factors
JON 4	NMT needs to verify that all hazard controls, including those from JON 3, are formally incorporated into specific implementing work control documents.	❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 5	NMT needs to evaluate the differences between the analysis in the current authorization basis and the as-found conditions in room 201B via the USQ process. This evaluation should include, as a minimum: ❑ Release of Pu-238 during handling, assuming failure of all packaging boundaries; ❑ Storage of Pu-238 packages outside of cages; ❑ Adequacy of the seismic restraints; ❑ Reconsideration of the absence of load limits for Pu-238 in room 201B.	❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)

No.	Judgment of Need	Related Causal Factors
JON 6	NMT needs to establish and implement a periodic, formal self-assessment program with performance-based criteria that will ensure work is performed safely.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 7	NMT needs to establish and implement a process to ensure that the flow down and effectiveness of worker hazard controls derived from and documented in the safety envelope (e.g., SAR, TSR, SER, HCP, SOP, etc.) have been verified prior to authorizing individual nuclear facility activities.	❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4)

No.	Judgment of Need	Related Causal Factors
		❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8)
JON 8	LANL needs to conduct a site-wide evaluation to identify all packages containing fissile materials and other radioactive substances, and ensure these materials are provided with the same degree of management attention as those currently identified in the DNFSB 2000-1 PEP, regardless of location or current use designation. The safety of the packages identified needs to be determined by comparison against established criteria, and prompt compensatory action needs to be taken for those found to be of question or concern. All containers identified in this evaluation need to added to the LANL Integrated Surveillance Program.	❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ LANL failed to identify all packages that should have been included in the program execution plan for DNFSB Recommendation 2000-1. (CC9) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)

No.	Judgment of Need	Related Causal Factors
JON 9	LASO needs to establish and implement a criteria-based process to periodically evaluate the flow down and effectiveness of worker hazard controls derived from and documented in the safety envelope (e.g., SAR, TSR, SER, HCP, SOP, etc.) for LANL nuclear facility activities.	❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 10	LASO needs to evaluate NMT-9 program activities for consistency to authorized budgets and DOE's life cycle (cradle-to-grave) management expectations.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)

No.	Judgment of Need	Related Causal Factors
		❑ DOE/NE and NNSA failed to establish clear funding and oversight responsibilities between DOE program elements for the NMT-9 work conducted by NNSA but funded by NE. (CC11)
JON 11	NNSA needs to validate the accuracy and completeness of LANL's revised 2000-1 PEP (after completion of JON 8) and ensure that compensatory measures are promptly instituted to mitigate the level of risk until all PEP activities are completed.	❑ LANL failed to identify all packages that should have been included in the program execution plan for DNFSB Recommendation 2000-1. (CC9) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)
JON 12	NNSA and DOE/NE need to develop a formal agreement defining the roles and responsibilities for the funding and oversight of safety-related activities associated with the NMT-9 work performed for NE missions.	❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10) ❑ DOE/NE and NNSA failed to establish clear funding and oversight responsibilities between DOE program elements for the NMT-9 work conducted by NNSA but funded by NE. (CC11)
JON 13	NNSA needs to develop a comprehensive set of requirements for the safe stabilization, storage, and disposal of Pu-238 bearing materials, to cover the full life cycle of this material.	❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ DOE and NNSA failed to provide comprehensive and adequate requirements and guidance for the packaging and storage of Pu-238 bearing materials. (CC12) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)

Type B Accident Investigation of the August 5, 2003 Plutonium-238 Multiple Uptake Event at the Plutonium Facility, Los Alamos National Laboratory New Mexico

1.0 Introduction

1.1 Background

On August 5, 2003 at 2:13 p.m., a continuous air monitor (CAM) alarm actuated in room 201B in the Plutonium Processing and Handling Facility (PF-4), Technical Area-55 (TA-55), at Los Alamos National Laboratory (LANL). Two LANL workers in the room at the time of the alarm immediately evacuated to an adjacent room. Both workers had detectable levels of external contamination and their nasal smear results indicated potentially significant intakes of plutonium-238 (Pu-238). Initial dose estimates based on the nasal swipes suggested that the radiation doses could be in excess of 10 rem Committed Effective Dose Equivalent (CEDE), which is twice the DOE's annual limit for occupationally exposed workers. (The most recent estimates, based on bioassay results, now indicate that the doses are on the order of 2 to 3 rem CEDE.)

On August 11, 2003, Ralph Erickson, Manager, National Nuclear Security Administration (NNSA), Los Alamos Site Office (LASO), ordered a Type B Accident Investigation of this incident in accordance with DOE Order 225.1A, *Accident Investigations* (see Appendix A for the appointment memorandum).

1.2 Facility Description

LANL occupies approximately 43 square miles of DOE land situated on the Pajarito Plateau in the Jemez Mountains of northern New Mexico. The closest population centers are the communities of Los Alamos, White Rock, and San Idelfonso Pueblo. The closest metropolitan center is Santa Fe, population approximately 70,000, located 35 miles away.

LANL's mission has been to apply science and engineering capabilities to problems of national security. As technologies, U.S. priorities, and the world community have changed, LANL's original mission has evolved from the primary task of designing nuclear weapons to the following five areas: (1) stockpile stewardship, (2) stockpile management, (3), nuclear materials management, (4) non-proliferation and counter-proliferation, and (5) environmental stewardship.

LANL currently consists of 49 active Technical Areas (TAs). TA-55 houses chemical and metallurgical processes for recovering, purifying, and converting plutonium and other actinides into many compounds and forms. Most of TA-55 is situated inside a protected area surrounded by a double security fence. PF-4, the scene of this accident, is one of five connected buildings located on 40 acres about one mile southeast of the central technical area. PF-4 maintains extensive capability for plutonium fabrication and processing.

The Regents of the University of California (UC) manage LANL under a management and operating contract with DOE. UC has managed the Laboratory since its inception in 1943. The NNSA Los Alamos Site Office (LASO), a part of the DOE, administers the contract with UC and oversees contractor operations at the site. The Deputy Administrator for Defense Programs (DP), NNSA, is the responsible program secretarial officer for LANL.

1.3 Nuclear Materials Technology Division Organization

The Nuclear Materials Technology (NMT) Division is responsible for the science, engineering and technology of plutonium and other actinides in support of the Nation's nuclear weapons stockpile, nuclear materials disposition, and nuclear energy programs. The Division is divided into several working groups based on function, as shown in figure 1-1.

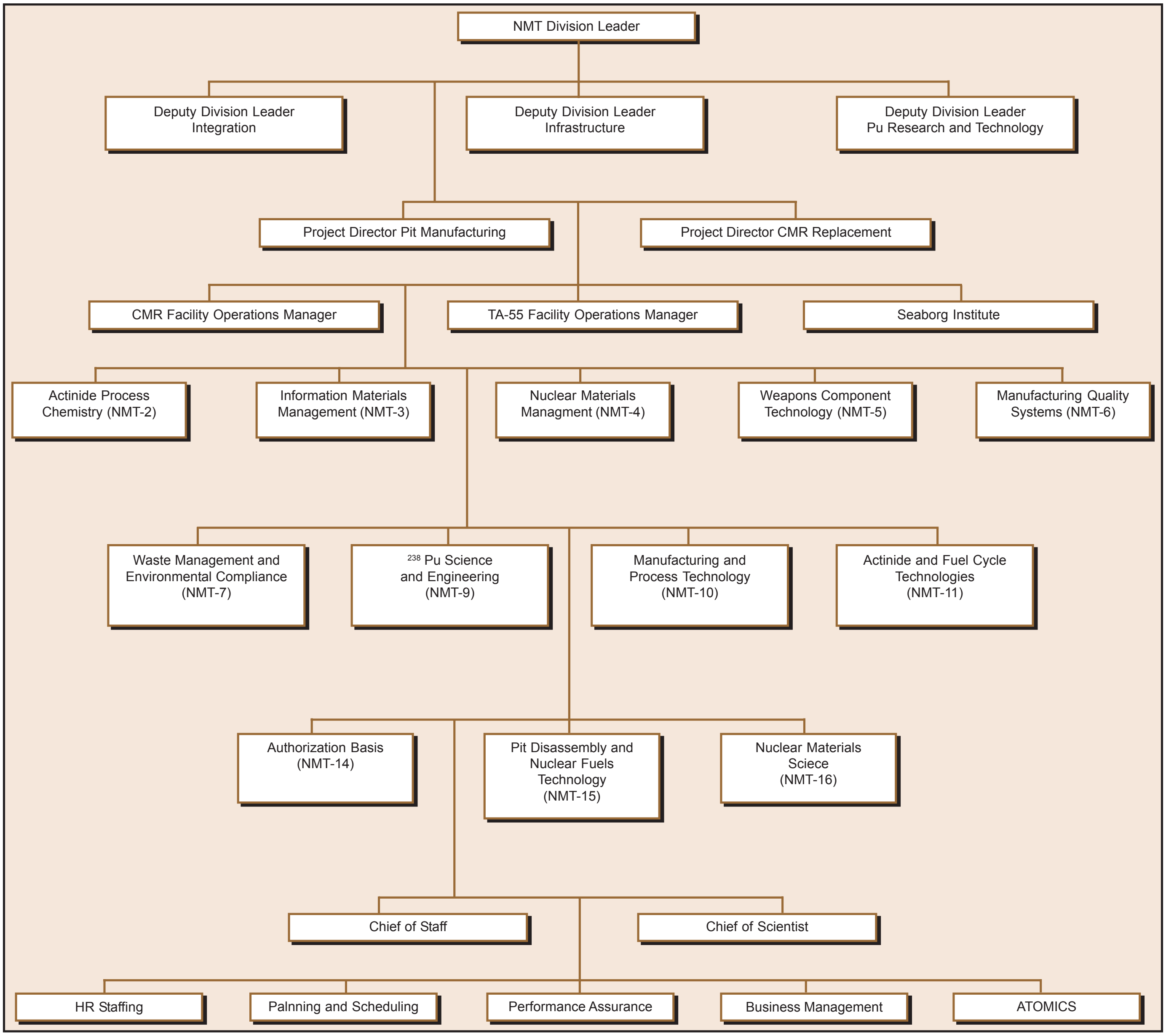

Figure 1-1 NMT Division Organizational Structure

The Plutonium-238 Science and Engineering Group (NMT-9) controls the room where the event occurred, and the two exposed workers were NMT-9 employees. NMT-9 is responsible for the development and application of Pu-238 heat sources for Defense Programs and space applications. For example, heat sources developed and fabricated by NMT-9, mounted in radioisotope thermoelectric generators (RTGs), provide electrical power for NASA's Cassini mission to Saturn.

1.4 Scope, Purpose, and Methodology

The Type B Accident Investigation Board (Board) began its investigation on August 13, 2003, and completed the onsite phase of its investigation on October 3, 2003. The scope of the Board's investigation was to review and analyze the circumstances of the accident to determine its causes. This investigation, performed in accordance with DOE Order 225.1A, *Accident Investigations*, also included an evaluation of the adequacy of the safety management systems of NMT, LANL, NNSA, and DOE as they relate to the accident.

The purposes of this investigation were to determine the causes of the accident, to identify lessons learned, and to reduce the potential for similar accidents at TA-55 and across the DOE complex.

The Board conducted its investigation using the following methodology:

- Inspecting and photographing the accident scene and individual items of evidence related to the accident.
- Gathering facts through interviews, document and evidence reviews, and inspections of the area.
- Conducting technical evaluations of items of evidence, as appropriate (most technical evaluations were conducted by LANL personnel under Board direction).
- Reviewing emergency and medical response.
- Using events and causal factors analysis, barrier analysis, and change analysis to correlate and analyze facts and identify the accident's causes (see box).
- Developing judgments of need for corrective actions to prevent recurrence based on analysis of the information gathered.

Accident Analysis Terminology

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

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

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

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

2.0 Discussion of the Accident

2.1 Room 201B

The room in which the event occurred, room 201B, is a 29-ft long by 14-ft wide room adjacent to a processing area used by NMT-9. The room is used predominantly for the storage of packages containing Pu-238 processing residues and contaminated materials generated by ongoing activities in NMT-9's processing gloveboxes. Exhibit 2-1 shows the general view of the room from one of the doors. The packages are stored in a variety of locations in the room, including four shelving units, referred to as "cages," which are labeled "A" through "D." At the time of the event, a section of room 201B was posted as a high radiation area, based on radiation levels in the vicinity of cages A, B, and C. This high radiation area was segregated from the rest of the room by using portable shielding, which is normally locked in place. Also, the four cages are restrained to the room walls due to seismic concerns. The most recent survey of the room demonstrated that there was no general removable contamination in the room before the event.

The packages being stored in the room are typically configured in a "can-bag-can" arrangement. The process for assembling these Pu-238 residue packages goes as follows. The material to be removed from the glovebox is placed inside of a can, which normally has a particulate filter in the lid. The lid is secured to the can with vinyl tape. That can is passed out of the glovebox directly into a thick plastic bag, which also has a particulate filter. The bag is then sealed and placed inside of a second can, and the lid of the outer can is taped down. At this point the package is assumed to be ready to be directly handled by personnel, and is ready to be placed into the room for storage or given to waste management (NMT-7) for disposal.

2.2 The Event

In preparation for an upcoming material control and accountability (MC&A) inventory, two NMT-9 employees (E1 and E2) entered room 201B on the morning of August 5, 2003 to perform a 'pre-inventory' of packages stored in that area. At that time, E1 and E2 inventoried the contents of cage D by comparing the package identification numbers to LANL's Materials Accountability and Safeguards System (MASS) listing, comparing tamper indicating device (TID) numbers to the TID log, and noting the location of each package.

After lunch, E2 proceeded to room 215 to retrieve the TID log and E1 went to room 204 to authorize an unrelated task as the room controller. On the way to room 201 after leaving room 215, E2 received verbal permission from the Radiation Control Technician (RCT-1) in the hallway to unlock the shielding and enter the high radiation area in room 201B in order to start the pre-inventory of cage C. E1 entered room 201B and E2 entered shortly thereafter. E1 and E2 removed the lock securing the shielding against cages A, B and C so that they could gain access to the area. After unlocking the shielding, the seismic restraints were removed from cage C. In order to gain access the contents of cage C, it was necessary to move the shielding and to roll the cage away from the room wall, as shown in Exhibit 2-1 and Figure 2-1.

The TID on cage C was removed and the cage was opened. E1 proceeded to read the package identification and TID numbers

Exhibit 2-1 Photo of room 201B from the doorway to room 201A.

off of the packages to E2, and E2 compared the numbers to the MASS printout and TID log while noting the location of each container. The top two shelves were inventoried without incident. E1 self-monitored for contamination at the completion of each shelf and no contamination was detected. During the evolution, E2 noted that their supplemental dosimetry (electronic dosimeters that provide a direct reading of external radiation doses) was reading higher than expected. E1 and E2 modified how they were performing the inventory to only check the MASS numbers and note the location of each package to minimize the time required to complete the task. Two packages were removed from the bottom shelf and placed on the floor to gain access to the other packages. While E1 and E2 were inventorying the third shelf, the CAM in the room alarmed, indicating that radioactive material had been detected in the room's atmosphere. At this point E1 and E2 immediately evacuated the room (see Figure 2-1).

2.3 Initial LANL Incident Response

When the CAM alarm sounded, E1 and E2 evacuated room 201B to room 201A where E1 discovered personal contamination with a hand and foot monitor. E2 opened the door to room 201 and verbally requested assistance from a radiation control technician (RCT). RCT-1 responded to room 201A. Also, upon activation of the CAM, the Operations Center made an announcement over the public address system to mobilize the radiation protection group. They mobilized resources to address decontamination of the employees, and containment of facility contamination. The RCT Supervisor coordinated the activities of several RCTs to ensure that resources were adequate for all phases of personnel and facility decontamination. E1 and E2's contamination was stabilized and they were sent to the decontamination facility. Personnel working in room 201 were evacuated to the hallway and monitored by RCTs. E1 and E2 were found to have skin contamination while RCT-1 had contamination on lab-issued clothing. These three individuals were the only personnel contaminated in the event.

The facility personnel decontamination room was activated and E1, E2, and RCT-1 were decontaminated. The RCT Supervisor ordered that room 201B was not to be entered and the room was "red-lit" consistent with facility procedures. E1 and E2 were briefed about bioassay requirements and taken to medical where they were given a risk briefing, including possible treatment options. Medical, in consultation with the LANL Dose Assessment Team, did not recommend further treatment. E1 and E2 agreed with this recommendation and were released. A critique was held the next day and the LASO radiation protection

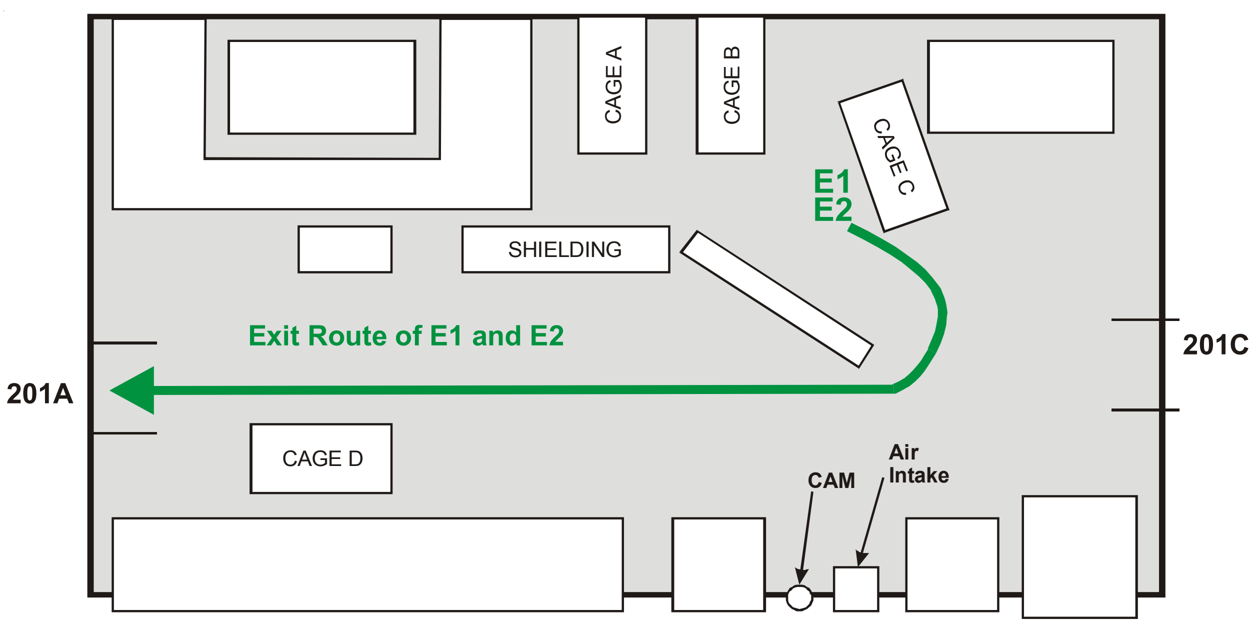

Figure 2-1 Locations and Exit Paths of Workers.

Plutonium

Plutonium (Pu) was the first manmade element produced on an industrial scale. Of the 15 plutonium isotopes, all of which are radioactive, scientists have focused their efforts on Pu-238 and Pu-239. The properties of Pu-239 make it a useful source for nuclear weapons and reactor fuel because of its high fission cross-section. The 87.7-year half-life and high alpha activity of Pu-238 make it an excellent heat source for applications such as radioisotope thermoelectric generators, since it produces about one-half watt per gram. The chemical properties of Pu-238 and Pu-239 are identical. However, the radioactive decay rate of Pu-238 is nearly 300 times higher than that of Pu-239.

The predominant radiation emissions from plutonium are alpha particles, which are of very high energy but do not penetrate materials significantly, and would not result in radiation fields outside of the packaging. However, all plutonium-bearing materials produce neutrons and gamma radiation to some degree, resulting in an external radiation hazard to facility workers. The two main mechanism for the neutron production are spontaneous fission events in the plutonium, and reactions between the plutonium alphas and light elements such as oxygen and fluorine.

The neutron emission rates vary with the isotope of plutonium and the chemical form, but in general, rates are higher for Pu-238 due to its higher specific activity. For this reason, shielding is often used to reduce the potential for worker exposure.

The Pu-238 oxide heat source fabrication process produces fine particles that are easily dispersed from surfaces as an aerosol. Once these particles escape containment, they can travel with the air currents throughout the room rather than settling directly in the area of the release. This tends to make decontamination more difficult as the particles migrate, often settling and contaminating surfaces after several hours or even days.

The principal human hazard from plutonium occurs when it is taken into the body. Plutonium taken into the lungs by inhalation will slowly be dissolved, but will be captured and retained by the liver and bone surfaces indefinitely. When plutonium is inside the body, surrounding tissues absorb the entire amount of energy associated with the alpha radiation. This mechanism accounts for most of the internal radiation dose. Since plutonium is removed from the body very slowly, a small intake can result in a significant internal radiation dose.

subject matter expert indicated that no entries would be allowed into room 201B, and that LASO was taking control of the room. Subsequently, LASO determined that a Type B Accident Investigation was required.

2.4 Consequences

The August 5, 2003 event generated consequences to personnel and facility. These consequences included potential health risks to affected personnel, their subsequent unavailability, as well as the unavailability of portions of the facility for programmatic use. The associated costs, to include the costs of the incident response, decontamination, and accident evaluation efforts are also consequences.

2.4.1 Dose and Personnel Contamination

The personnel (E1, E2) in room 201B at the time of the release received measurable Pu-238 intakes. Preliminary estimates indicate that the resulting doses may be over the DOE's regulatory limits. Exposure to radiation is assumed to result in a proportional increase in the individual's long-term cancer risk, although this has not been proven at low doses. Based on the doses projected in this case, the increase in risk is likely to be very small or negligible compared to the normal cancer incidence rates. The event also resulted in skin contamination of E1 and E2 that required decontamination, although skin contamination normally presents negligible health consequences. The availability of several RCTs, a decontamination room, and adequate supplies aided this effort, which was accomplished with no detectable contamination remaining when the employees were released.

The primary follow-up action to this accident with respect to the affected workers will be the continuing process of estimating their CEDE. The process for determining the dose from a plutonium intake could take six months to a year of periodic bioassay results and evaluations before a final dose assignment can be made. A key parameter in this dose assessment is the solubility of the plutonium-bearing material in human fluids. The solubility of the material determines how quickly the plutonium is redistributed through the body and absorbed in various tissues, especially bone surfaces, or is eliminated from the body by excretion. The reason for the lengthy dose assessment process is to collect sufficient data to evaluate this redistribution process. Table 2-1 contains the range of potential doses for the affected workers as a function of the solubility of the material, and LANL's preliminary estimate based on early bioassay results, using the data available at the time of this report.

The DOE's annual radiation dose limit for workers is five rem total effective dose equivalent (TEDE). These limits are specified in 10 CFR Part 835, *Occupational Radiation Protection*. Due to the long-term nature of these doses, they do not represent an immediate threat to the health of the workers. However, the long-term risks are indeterminate and may represent an increased risk of developing cancer later in life, although the increase in risk is likely to be very small or negligible compared to the normal cancer incidence rates.

2.4.2 Airborne Radioactive Material Concentration

The release of Pu-238 in room 201B was entrained in the room air and spread quickly. This was evidenced by subsequent CAM alarms in room 201C and room 204. The spread to room 201C could be expected due to the door between the two rooms, and the spread to room 204 was apparently via small cable penetrations in the wall between the two rooms. The particles' ability to follow air-paths was also demonstrated by CAM and fixed-air sampling (FAS) results. The potential inhalation dose, as represented by the three FAS for room 201B, ranged from 817 to 3268 DAC-hrs. (The unit of DAC stands for "derived air concentration", a DOE regulatory term. For comparison, a person breathing air with a concentration of 1 DAC for 2000 hours would be expected to receive a dose of 5 rem CEDE, the DOE regulatory limit.) The highest FAS result would correlate to a potential dose in excess of

Table 2-1 Preliminary Dose Estimate (CEDE) to Affected Workers

	Dose (rem CEDE)		
Worker	**Upper Range**	**Lower Range**	**Current Estimate**
E1	24	0.3	3.0
E2	12	0.6	1.8
RCT-1	<0.03	0	0

Units of Radiation Dose

Since 1992, DOE's radiation dose limits have been expressed in terms of total effective dose equivalent (TEDE). This change was made to improve the control of doses from internally deposited material by equating the risk to the individual from internal and external exposures. The TEDE is the sum of the deep dose received from radiation sources outside the body (e.g., from exposure to x-rays) and the committed effective dose equivalent (CEDE), which is the dose received from taking radioactive material into the body (typically from inhaling or ingesting radioactive material). The CEDE is the calculated dose the individual will receive during the 50 years after the material is taken into the body. Some radioactive chemicals, such as tritiated water vapor, do not remain in the body for long periods of time. Others, such as plutonium oxide, remain in the body for very long periods of time and continue to deliver dose to the individual at a fairly constant rate over an extended time.

annual limits. This data indicates that the plutonium released in this incident was highly mobile and remained airborne long enough to migrate inside room 201B and adjacent rooms via air currents. Therefore, releases of this type can affect personnel in adjacent rooms. Once the airborne release settled on surfaces, it did not become airborne again during reentries that were conducted for this investigation. These attributes are consistent with the material being very fine particles, which is not unusual for aged Pu-238 particles that break down via decay product recoil damage. Based on the air sampling results and the residual contamination levels in the room, the Board estimated that the quantity of material released to the room was in the range of 2 to 9 micrograms of Pu-238.

2.4.3 Facility Contamination

Removable surface contamination was found throughout room 201B at or above the 1000 dpm/100 cm^2 level. However, localized contamination was over 100 times this level near the release point. A significant decontamination effort will be required due to the large surface area from the number of packages and mobility of Pu-238, requiring multiple entries to remove all contamination. Operations in room 201B will require increased controls to perform work including enhanced Personnel Protective Equipment (PPE) until the room is stabilized. The restricted access to the room and the level of effort necessary to restore the area to normal operations will result in additional costs to the facility and may result in additional programmatic impacts.

2.5 Accident Reconstruction

At the time of the event, there were no other activities ongoing in the room, and only limited work occurring in the adjoining areas. Therefore, there was no evidence that the release may have been due to something other than a failure of one or more of the packages in the room. The CAMs in two adjoining rooms alarmed, but they both were subsequent to the initial alarm in room 201B, and could be explained by a release occurring in room 201B. Consequently, it was apparent that a package had failed in the proximity of where E1 and E2 were working. However, neither E1 or E2 noticed anything unusual while working in the room, nor did they note any defects or other abnormal conditions with the packages they were handling.

Since there was no obvious mechanism that could have led to the release, the Board, with LANL's assistance, spent a significant amount of effort attempting to identify which package had failed, and how the failure had occurred. For the release to occur, the Board postulated that three basic conditions must have been present:

- Source Material – there must have been radioactive material of the proper form and quantity that could be dispersed into the atmosphere;
- Failure of the containment boundary – a pathway must exist for the material to escape the containment for dispersal into the atmosphere; and
- Motive Force – there must be some form of energy to cause the release and suspension of the material in the atmosphere.

In this situation, it was clear from analysis of the air samples that the release had involved Pu-238, and that the only source of Pu-238 in the room was that contained in the packages. Therefore, the source material was self-evident. However, the boundary failure and the motive force were not apparent.

The Board developed a postulated release scenario to help focus their search for the leaking package and its failure mechanism. First, it was recognized that although there were three boundary layers of the packaging (inner can, plastic bag, and outer can), it might only be necessary for two boundaries to fail. This was due to the fact that while the bulk of the Pu-238 was contained within the inner can, the exterior of that can would likely have significant Pu-238 contamination on it due to its presence in a contaminated glovebox. Rough estimates of the quantity released suggested that this surface contamination could represent an adequate amount of material to lead to the release. Therefore, the Board postulated that, as a minimum only the plastic bag and the outer can would have to fail to provide an adequate leak path for the plutonium. However, the Board also recognized that without an adequate motive force, this leak path would likely only lead to localized contamination on the exterior of the outer can, and probably would not lead to the rapid and widespread dispersal of material into the room atmosphere that was actually observed. Therefore, the Board also postulated that there was likely to have been a buildup of gas pressure within the outer can, coupled with a rapid failure of the outer can, allowing a quick venting, or 'puff,' in order to disperse the material.

A failure of the bag could easily be accomplished, since the bags were known to degrade with time, especially in the presence of heat, radiation, or acids. In this case, all three of these would likely be present in the package. Many of the packages in the room contained contaminated cheesecloth from cleaning the glovebox interiors or wiping up spills, and therefore it was probable that nitric acid, cleaning solutions, water, and possibly other chemicals were present. Furthermore, radiolytic and thermal decomposition of the cheesecloth was known to generate carbon monoxide, carbon dioxide, and water vapor. Given the particulate filters on both the inner can and the plastic bag, vapors of these chemicals would pass easily across the boundaries and contribute to the degradation of the bag. The interior of the outer can would also be exposed to these vapors, and therefore corrosion of the interior surface of the outer can could be anticipated.

There was no particulate filter on the outer can, as the facility assumed that the outer can would "breathe" through seams and around the slip-on lid (these cans were not designed to be air tight). However, the Board noted that the facility's practice was to fully tape the lid onto the outer can with a plastic tape. Therefore, the Board postulated that the tape, coupled with the formation of rust on the interior surface of the outer can, would tend to restrict the outer can's ability to breathe. This restriction could then allow a minor pressure buildup within the can due to the gases being generated from the decomposition of the bag, inner can, and cheesecloth. Finally, the Board postulated that a small physical disturbance to the package, such as simple handling, could result in a breach of some of the rust in a seam, creating a vent path for the pressure inside the can, and the motive force for the dispersal. A summary of the Board's postulated release scenario is shown in Figure 2-2.

The Board and members of the NMT organization conducted an initial reentry into room 201B to determine the as-found conditions. Exhibit 2-2 shows the storage configuration of the packages in the cages. The reentry team validated that the room conditions had not changed, the CAM was not alarming, and the contamination levels had not changed. As expected, the reentry team found the two packages (P1 and P2) on the floor as they had been left when E1 and E2 evacuated the room during the event.

A contamination survey conducted by the reentry team showed that the general contamination in the room ranged from 500 – 10,000 dpm/100 cm^2 (all readings are for total alpha radiation, unless as noted), but that there was a 600,000 dpm/100 cm^2 "hot spot" on the floor directly in front of cage C (Exhibit 2-3). This location is where the two employees were standing when the CAM alarm sounded. In addition, the survey showed that one of the two packages on the floor, P2, had about 200,000 dpm/100 cm^2 on its bottom. Also, the survey identified a third package, P3, on the bottom shelf that had a reading of 200,000 dpm/100 cm^2 at the junction between the seam along the side of the can and the seam for the can's bottom (Exhibit 2-4). No other package could be found that showed contamination at these levels. Figure 2-3 summarizes the results of the reentry team's survey of cage C. The reentry team conducted further visual observations of the packages, looking for obvious signs of a leak path, but none could be identified visually.

As shown in Figure 2-3, package P3 on the lower left shelf of cage C had the highest contamination reading of the packages in cage C (200,000 dpm/100 cm^2). This spot was located where the seam connected to the bottom of the outer can. The seam was oriented towards the front of cage C, pointing towards the 600,000 dpm/100 cm^2 area on the floor. From the interviews, it was determined that E1 had placed two packages on the floor and was handling another package from the third shelf when the CAM alarm sounded. (The inventory checklist was inadvertently disposed of during post-event cleanup and neither E1 nor E2 were sure of which packages they had already handled; consequently the Board could not determine exactly which packages had been handled before the CAM alarmed, other than the two on the floor.) Based on its proximity, the Board believed that E1 had worked with package P3 prior to the evacuation.

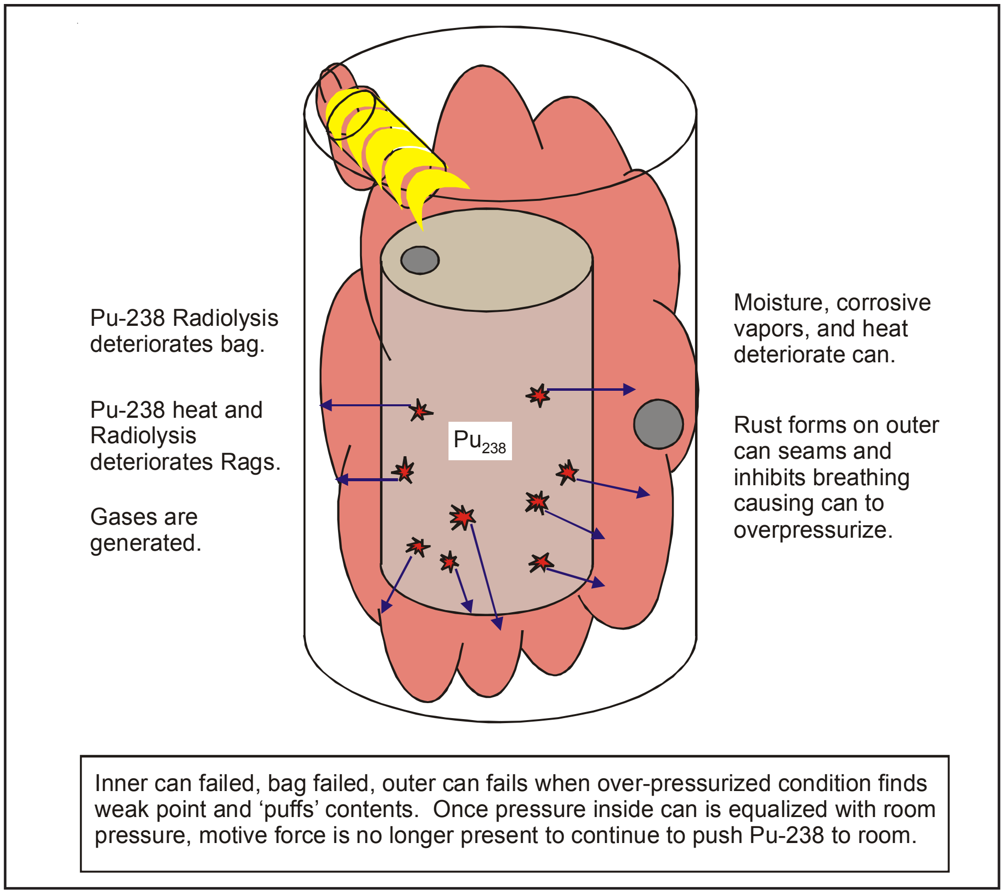

Figure 2-2 Package Failure Scenario

Exhibit 2-2 shows the storage of packages in the cage.

Exhibit 2-3 shows reentry team member pointing out the hot spot location.

Exhibit 2-4 shows a package on the floor and a suspect package in the cage directly in front of the hot spot location. Note the position of the sidewall seam on the suspect can.

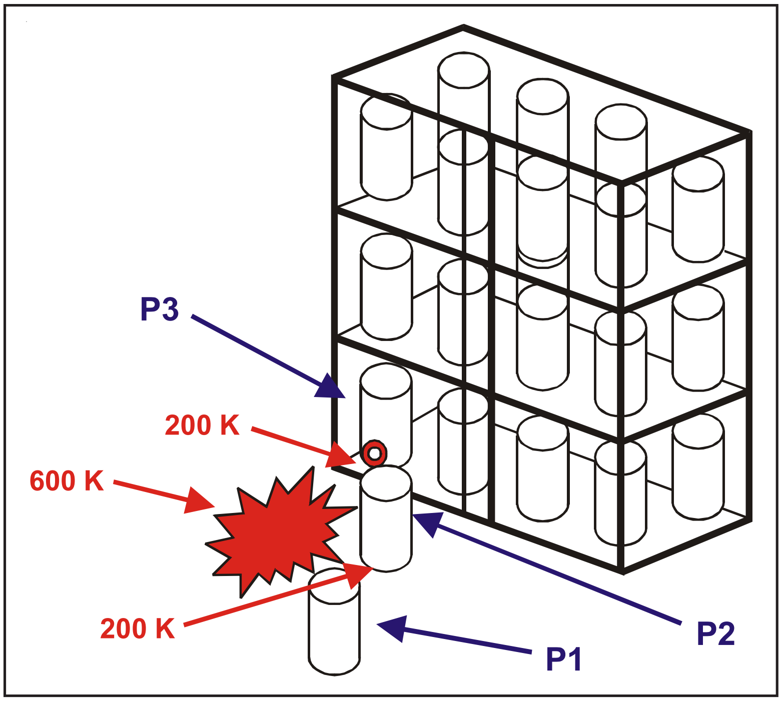

Figure 2-3 Schematic of high contamination readings around cage C.

The reentry team removed the two packages on the floor (P1 and P2) and P3 by placing wet cheesecloth on them to control the further spread of the contamination, and then placing them in clean bags while moving them to an adjoining room. The three packages were then introduced into a glovebox hood in a nearby room. The next day, an NMT employee observed that the packages were beginning to show signs of corrosion on the exterior of the outer cans, apparently due to the wet cheesecloth. The packages were removed from their bags, contamination levels were checked, and then the packages were wiped down and placed into new bags in the glovebox hood. The contamination level on the seam of P3 was found to have increased from 200,000 to 400,000 dpm/100 cm^2, but there was no apparent change in the contamination levels of P1 or P2. The contamination levels inside the hood increased significantly (to levels greater than 1,000,000 dpm/100 cm^2) after the operation. This observation further focused the Board's attention on P3 as the likely suspect. The Board, in conjunction with NMT personnel, began to develop plans to open the three packages and examine the condition of the contents.

The facility's records were reviewed to determine the contents of the three packages removed from cage C. Those records are not of sufficient detail to determine the exact contents or origin of the packages, but rather the packages are grouped into general categories based on their contents, and the creation date and plutonium mass are recorded. Table 2-2 lists the relevant information for the three packages.

In preparation for opening the packages, radiographs were taken of all three packages. From the radiographs, it appeared that two of the packages, P1 and P3, had evidence of loose material in the region between the inner and outer cans. The bag between the inner and outer cans does not display well in a radiograph, and therefore it was not clear as to whether the material was inside or outside of the bag between the two cans. Also, loose rust from the corrosion of the can surfaces could be present, and therefore one should not assume that the material necessarily came from the inner can. Nonetheless, the bottom of the inner can of the package P3 appeared to have failed, releasing materials directly onto the bag inside the outer can (see Exhibit 2-5).

Table 2-2 Inventory Records of Cans Removed from cage C.

ID	Creation Date	Category	Pu-238	Recorded Remarks
P1	8/10/1998	Rags	9.7 g	"Rags for Discard"
P2	10/17/1996	Combustibles	20.5 g	"Exceeds EDL, Certification is revoked. Contact NMT-7 Waste Mgmt." [Note: EDL is the Economic Discard Limit.]
P3	8/20/1996	Rags	13.3 g	"Rags for Discard"

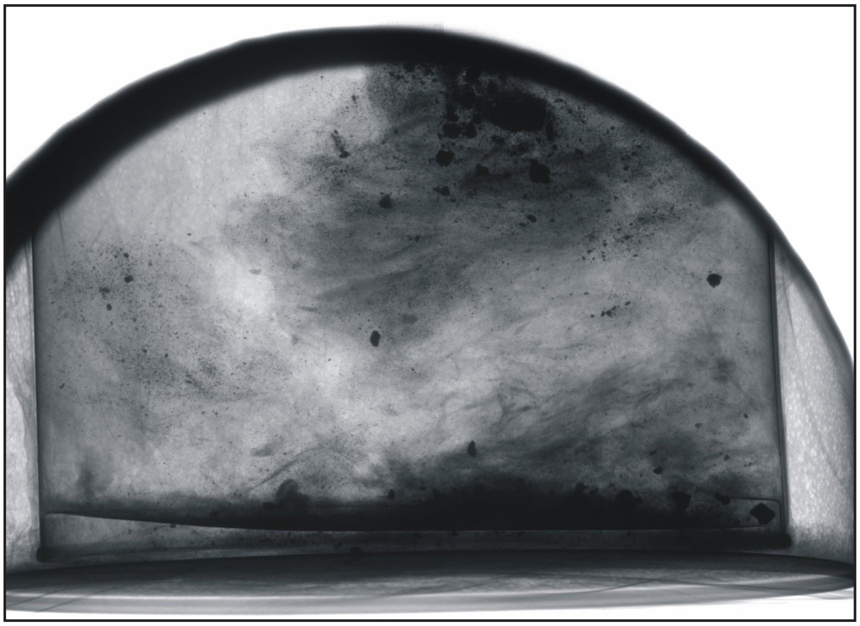

Exhibit 2-5 shows the Digital Radiograph of P3. Note the angle of the bottom of the inner can.

packages, but no practical method could be identified given the difficulties of working with these packages inside of gloveboxes.

The packages were disassembled in an inert-atmosphere glovebox to evaluate their contents. When the tape was removed from the lid of the outer cans, rust deposits were observed on the tape where the tape was in contact with the lid seal (see Exhibit 2-7). In all three packages, the buildup of rust in the gap between the outer can lid and the lip of the can was extensive. In fact, for one of the packages (P1) it was necessary to pry the outer can lid off because of this rust buildup. Samples of the outer can rust were analyzed with a scanning electron microscope to determine their content. As expected, iron oxide was the major component, however there was a notable amount of chlorine present in the samples, which was likely due to the degradation of the PVC bags. The hydrogen chloride generated from the bag would combine with the water vapor and form hydrochloric acid, which would then attack the outer can. This would accelerate the corrosion process.

The first step in opening the packages was to puncture the outer can lids with a device designed to sample the packages' internal atmospheres, as shown in Exhibit 2-6 (only the internal atmospheres of P1 and P3 were sampled). Carbon monoxide, carbon dioxide, methane and hydrogen chloride gases, and nitric acid, toluene, and water vapor appeared to be present. (This analysis was restricted in its qualitative and quantitative capability due to limitations of the equipment that was available able to handle plutonium-contaminated samples. For example, both hydrogen and helium would be expected to be present, but the analytical technique could not evaluate them.) These results could be expected under these conditions. The nitric acid is likely to be residual acid from the rags, and the carbon monoxide and dioxide, methane, and water vapor would be generated during the decomposition of the cheesecloth. The hydrogen chloride and toluene are products of the radiolytic decomposition of the plastic bag, which is made of polyvinyl chloride (PVC). The Board also wanted to measure the atmospheric pressure inside the

Exhibit 2-6 shows the head gas sample being taken on one of the packages.

Exhibit 2-7 shows the rust on the tape and under the lid of the outer can.

In addition to the rust around the lid of the outer can, the interior of the P1 and P3 outer cans showed extensive corrosion, although not to the point of breaking through the wall. However, visual inspection clearly showed that the rust had formed a crust around the bottom edges of the cans. It should be noted that the P2 outer can did not demonstrate the same degree of corrosion as P1 and P3 on the outer can, which is likely due to the different type of materials inside the can.

The bags used to contain the inner cans were visually inspected and samples were taken for further analysis. The bags in packages P1 and P2 were severely discolored brown and embrittled in places but appeared to be intact. When the bag and inner can were removed from the P3 package, the bag was also severely discolored and embrittled, but was also found to have a 1 – 2 inch hole in the bottom of the bag along the seam (Exhibit 2-8). This hole appeared to be associated with a pair of stress points that were formed by the stretching of the bag around the inner can. Since the bag was apparently intact when the package was originally created, the Board assumed that the bag degraded with time until the failure occurred at a stress point along the bottom seam. If the bag had been torn before use, this would likely have been detected during the bag-out process (the bags are tested for leaks before they are used, and the package is checked for contamination before being placed in the outer can). Optical microscopy of the failed section also suggested that the failure was due to a tear rather than an inadequate fabrication of the bag or a cut from a sharp edge.

Next, the inner cans were visually inspected. Package P2 was found to be intact and in reasonably good condition, as shown in Exhibit 2-9. Contrary to the condition of the P2 inner can, both P1 and P3 inner cans showed significant corrosion resulting in failures. A sizeable hole was also identified on the lid of the inner can of P1 (Exhibit 2-10). When the bag was removed from P3, the bottom of the inner can of P3 was found to be separated from the sides of the can, consistent with the radiographs. Further visual observation of P3 showed that the lower section of the inner can sidewall had completely corroded through in multiple points (Exhibit 2-11).

Exhibit 2-8 shows the bag failure of P3.

Exhibit 2-9 showing condition of P2 inner can.

Exhibit 2-10 shows the inner can lid failure of P1.

The contents of the cans were examined both visually and with optical microscopy. The cheesecloth in P1 and P3 had undergone significant decomposition, as would be expected. Since the contents of P2 were of a different composition, apparently mostly glovebox sweepings and general debris, it was more difficult to assess their level of degradation. This was consistent with the lower level of degradation of the P2 inner can as compared to P1 and P3.

In order to evaluate the potential impact of corrosion on the seams of the outer can, the Board conducted a simple experiment. A few ounces of water were placed into a similar, but new outer can, and the can leaked at the junction between the side seam and the bottom seam. (The same location as the leak point for the P3 package.) The can was allowed to dry out, and within two days a light layer of rust formed around the bottom seam. At this point more water was added to the can, and the can did not leak as it had before, even after the can sat for a few days. Finally, a lid was placed on the can and the lid was taped down. Then, the can was placed in the sun, and the increased pressure from the warming of the can began to push the water back out of the same leak point again.

The Board concluded that the P3 inner can, PVC bag, and outer can failed. The inner can had obviously corroded to failure, and the PVC bag had decomposed and failed at a stress point. The outer can did not have an obvious failure point, but the Board concluded that the significant amount of rust around the lid and lower seams on the interior of the outer can had restricted the outer can's ability to "breathe," thereby allowing the gases generated from the decomposition of the contents to build up pressure. Furthermore, the Board concluded that the handling of the can during the pre-inventory activity likely dislodged the rust buildup on the outer can allowing the pressurized contaminated atmosphere to vent through the seam junction.

The Board noted that, based on both the evidence discovered and the understanding of the underlying degradation processes, the failure mechanisms for each of the three layers of the package could proceed independently of each other. In other words, the degradation of each boundary did not depend on the breaching of any other boundary in order to begin or progress to failure. Therefore, the Board concluded that the failure mechanisms for each boundary were proceeding simultaneously and independently, thereby circumventing the intention of a multiple-barrier packaging design philosophy. The result of this simultaneous progression to failure would be to significantly reduce the actual time-to-failure for the package from what would be expected in a sequential failure mechanism, where each boundary would be attacked only if the previous boundary failed.

Exhibit 2-11 shows the inner can failure of P3. Note that this view is from the bottom of the can

3.0 Accident Facts and Analysis

3.1 Incident Response

The incident response to this event included the immediate evacuation of personnel, Operations Center notifications, Operations Center recording of data, the decontamination of personnel, and medical counseling and bioassay of exposed personnel (E1, E2, and RCT-1).

3.1.1 Immediate Evacuation

E1 and E2 immediately evacuated room 201B to room 201A when the CAM alarmed. RCT-1 was summoned to room 201A to help monitor their decontamination. These individuals remained in this area until a step-off pad was set up. The Board identified that the decision to evacuate to room 201A was not consistent with site training, which requires evacuation to the corridor. Interviews with numerous personnel agreed with the actions taken by E1 and E2 to evacuate to room 201A versus the corridor. The personnel consistently stated that an evacuation to the corridor would have unnecessarily spread contamination. The Board identified that room 201A was not an ideal evacuation location due to unknown air flow between room 201A and room 201B and the lack of real time air monitoring in room 201A. An evacuation to the corridor would have ensured that no further internal dose occurred since it is held at a higher air pressure than the laboratories, and is on a separate ventilation system. It was later identified that air does flow from room 201A to room 201B. In addition, from the bioassay data from RCT-1, it seems that room 201A was a safe location, although this was not known at the time. Had the airflow been unfavorable, additional internal dose to E1, E2 and RCT-1 could have been caused by the evacuation to room 201A. The Board concluded that, while there may be a logical basis for the actions taken, the decision to evacuate to room 201A was inconsistent with site training and could have resulted in additional internal dose to the affected workers.

3.1.2 Operations Center Activities

The Operations Center is responsible for receiving, logging and announcing CAM alarm events. The Operations Center receives electronic notification of CAM alarms and has a response instruction that dictates entries into a logbook. The Board reviewed the Operations Center log versus their alarm response instruction. The Operations Center accurately logged the room 201B CAM alarm; however, room 201C and room 204 CAM alarms were not logged in although they were received electronically. The Operations Center also did not log CAM count data as required by the CAM Alarm Response Instruction. The room 201B CAM alarm (but not room 201C or room 204) was announced over the PF-4 public address system. The Health Safety and Radiation Protection Group (HSR-1) was notified based on the Operations Center log, however the on-duty supervisor was not notified by the Operations Center as required by the Alarm Response Instruction (although the on-duty supervisor would have heard the public address system announcement). The Board concluded that the actions of the Operations Center personnel were inconsistent with the CAM Alarm Response Instruction.

3.1.3 Decontamination of Personnel

Upon announcement of the CAM activation, numerous RCTs responded. The RCT supervisor took the lead in directing resources to ensure adequate support in preparing E1 and E2 for moving to the decontamination (de-con) room and for staffing the de-con room. The RCT supervisor also took the lead in directing decontamination efforts, especially those that could result in further intake. Taping over the coveralls, placing a skullcap over contaminated hair, and removing gloves minimized the further spread of E1 and E2's contamination. The Board noted that E1 and E2 were only wearing one pair of gloves, contrary to the requirements of the RWP. The employees were then taken to the de-con room where coveralls were removed and skin contamination was washed off. RCT and personnel contamination monitor surveys confirmed that the employees were successfully decontaminated. The Board concluded that the decontamination was successful in removing personnel contamination without increasing internal doses.

3.1.4 Medical Counseling/Bioassay Follow-up

After leaving PF-4, E1 and E2 were briefed by the bioassay coordinator and informed of the follow-up bioassay requirements. E1 and E2 were escorted to the Health, Safety, and Radiation Protection Division Occupational Medicine Group (HSR-2) in a government van. The briefing included the HSR-2 Medical Director, HSR-12 Internal Dosimetry representative, NMT-9 Group leader, and HSR-1 TA-55 RCT Team Leader. The employees were briefed regarding the magnitude of the dose based on available data (nasal swipes). HSR-2 also briefed the employees about potential medical treatment. For this event, HSR-2 did not recommend treatment due to the dose and expected chemical form (oxide), which is less responsive to the treatment. The employees agreed with this recommendation and declined the treatment. They were then released. The testimony of participants indicated that the information provided was appropriate. The Board concluded that the employees were appropriately informed of the risks, possible treatment options, and bioassay follow-up requirements.

3.2 Technical Basis for Interim Storage of In-process Material

The LANL requirements for establishing an Authorization Basis for the work in room 201 B consists of the following:

- A Documented Safety Analysis (DSA) per the requirements of 10 CFR 830 subpart B;
- Hazard Control Plans (HCPs); and
- Standard Operating Procedures (SOP) and Work Instructions (WI).

The DSA includes a Preliminary Hazard Analysis (PHA) that evaluates potential initiating events based on the types of activities conducted within the facility and quantitatively addresses the probability of these initiating events and the consequences of any resulting hazard to the public, the environment, and the workers. The resulting accident scenarios are grouped based on the type of initiating event (such as fire or earthquake) and the type of hazard that is created (such as a radiological release). From the PHA, bounding accidents are selected for those events with the highest unmitigated risk and a quantitative analysis is conducted to determine if safety class controls are needed to protect the public, the environment, and workers.

The HCPs are intended to focus more on worker hazards associated with specific work activities and typically will identify controls such as procedures and training to mitigate these worker hazards. The SOP and WI provide the specific controls related to conducting the work that is necessary to protect workers and if applicable to protect the public and or environment.

The current TA-55 DSA is the July 1996 version of the Safety Analysis Report (SAR) approved by the DOE in December 1996. Section 3 of the SAR "Hazard Analysis" includes an evaluation of possible scenarios leading to a Material Release Radiological (MRR). In the Hazard Analysis MRR scenario "Failure of Plutonium Storage Containers During Movement Resulting in Worker Uptake and Room Contamination," was categorized as an anticipated event with a probability of 1 in 10 to 1 in 100 operating years, with the anticipated consequence of the worker's radiation uptake exceeding the DOE's annual radiation dose limit. This event was judged to be the bounding MRR event within its frequency bin, and as a result was further analyzed in the SAR's Section 3.4.2.6, "Operational Accident- Plutonium Release from a Degraded Storage Container."

In the "Plutonium Release from a Degraded Storage Container" analysis, the SAR stated the bounding event was initiated by the accidental drop of plutonium dioxide storage container during handling in the TA-55 Vault. This location was chosen since the highest quantity of special nuclear material (SNM) was stored in the vault and numerous handling operations were conducted to perform inventory of the material.

The SAR acknowledged that "some storage containers in the vault have degraded inner containers so the impact of the outer container during movement or from being dropped may release a portion of the contents and a worker will be in the immediate area of release." Additionally, the SAR stated, "Although either a degraded or non-degraded container could be involved, the likelihood of a failure is higher for storage containers that have undergone significant deterioration from chemical or physical changes in the SNM."

The analysis stated that important mitigative and preventative features for this release include "the design of the storage containers used for SNM; administrative limits placed on material quantity by form for storage containers; procedures which govern the safe handling of SNM; and the multiple stages of HEPA [High Efficiency Particulate Air] filters (public protection)." The analysis also specifically recognizes potential problems with material stored in containers that do not provide a hermetic seal (such as the slip-lid cans). Problems listed include the following:

- The metal may oxidize and cause inner containers to bulge or burst.
- Corrosion of metal contained in plastic may occur as a result of reaction with chemical species produced by alpha particle induced decomposition of the organic compounds in plastic.
- Degradation of taped seals on containers and plastic bags around the inner containers may make the packages susceptible to rupture during handling or if dropped.

The SAR determined that if 4.5 kg of weapons grade plutonium oxide was dropped from 10 feet then 2.7 grams of plutonium would be released. The analysis did not take credit for the inner container (assumed to have been ruptured by the plutonium oxidation reaction), the inner plastic bag (assumed to have deteriorated), or the outer package (assumed to be a slip-lid can with degraded seal). The unmitigated release (no HEPA filtration present) was 8.1 rem CEDE. Since this was less than the evaluation guidelines, Safety Class controls were not required. For worker doses, the analysis stated, "the worker involved in the accident would be exposed to a significant inhalation dose, most likely in excess of the MPBB [maximum permissible body burden]."

The Board concluded that NMT Division's analysis of a plutonium release from a degraded storage container was inadequate due to the following:

- The determination of the frequency bin and subsequent risk of this event did not account for the known degradation of the packages.
- Storage in room 201B was not acknowledged in this analysis and as a result the source term does not address Pu-238, which has a much higher specific activity than Pu-239.
- The analysis assumes mitigative features of administrative limits on materials and design of the packages that are present for storage in the vault. However, those mitigative features were not applied to storage in room 201B.

In 1994 LANL conducted a Type C accident investigation into a pair of events, one of which involved materials stored in room 201B (this investigation is discussed further in a later section of this report). The Type C Investigation Board determined that, "The current storage of waste cans containing plutonium–238 contaminated cheesecloth in room 201B poses an unevaluated, potential hazard," and recommended that the SAR "evaluate the use of room 201B to ensure that its use as a staging and storage area for Plutonium-238 contaminated waste containers is within the safety envelope of the facility." The 1996 SAR subsequently evaluated the consequences of a fire and/or earthquake in room 201B in order to determine if an appropriate material limit needed to be placed on the room (there was a limit of 500 g imposed on the room at that time, but it was based on criticality concerns for Pu-239, and was deemed to be not relevant to the storage of Pu-238).

The SAR concluded that the consequences of the Evaluation Basis Fire (EBF) would bound a fire in room 201B. This conclusion was based on a qualitative analysis that determined that although the material at risk in room 201B may be greater than in the EBF, the combustible material loading in the EBF is so much larger that the overall release from the EBF would be higher. As a result, a quantitative analysis was not conducted for a fire in room 201B and a Pu-238 specific material limit was not established (this decision resulted in the removal of the 500 g limit on the room).

The Evaluation Basis Earthquake accident (EBE) analysis used 63 gloveboxes loaded with 500 grams each of Pu-238 oxide to determine the offsite dose consequences. The analysis did not include any of the ancillary storage areas like room 201B. To address room 201B, the SAR included a qualitative analysis that if the material in room 201B were to be displaced during the EBE, some material could ignite cheesecloth and would need to be added to the source term. However, this additional amount was judged to be insignificant. Rather than do a quantitative analysis to support this engineering judgment, a commitment was made to seismically qualify the storage cages so the material in room 201B would not contribute to the source term in the event of an EBE.

Condition of Approval (COA) #7 from the December 1996 DOE Safety Evaluation Report stated the seismic capacity of the storage cages in room 201B should be verified and included as a Design Feature (DF) in the Technical Safety Requirements (TSRs). Appendix B "Design Features" of the currently approved version of the TA-55 TSR (September 1999) includes the "waste storage racks in room 201B" as a general DF. The design of the cages included "seismic restraints" intended to keep them from falling over during an EBE. However, there was no DOE review to determine whether these restraints were adequate. Additionally, the Board noted that one-third of packages (and one-third of the Pu-238 mass) were on the floor and not in any of the four storage cages. The Board concluded that the storage of packages on the floor represented a condition that was not addressed by the SAR analysis.

The Board concluded that although the storage cages were listed as a general Design Feature, NMT did not identify specific Functional Requirements for them. As a result, the TA-55 TSR did not include in-service inspections (ISIs) to verify that the storage cages were meeting their intended function. Additionally, the Board concluded that DOE LASO did not independently verify that the storage cage design was adequate, and NMT-9 did not identify the fact that the seismic restraints were TSR level controls and subsequently establish requirements for ensuring they were promptly reinstalled when removed to conduct inventory activities. During the Investigation, the Board discovered some of the restraints to be broken or inoperable. This is discussed further in Section 3.5. Lastly, NMT did not analyze the contribution to the offsite dose consequences from the packages on the floor that were not restrained.

The Board also concluded that NMT did not evaluate the risks to workers associated with package failures even though the SAR acknowledged that a significant quantity of Pu-238 was stored in room 201B, and there was no clear long-term disposition path for the material. As a result, NMT-9 did not define a limit for the amount of material in the room; did not identify the types or quantities of material and chemicals that could be stored in the packages, e.g., cheesecloth and nitric acid, and did not determine the length of time the material could be safely stored without formal surveillances.

The PHA is used as a basis to determine what types of events need to be further analyzed in the SAR (generally hazards to public and environment) and what hazards (primarily hazards to workers) need to be addressed in lower tier documents such as hazard control plans and work instructions.

Individual processes are evaluated through a Process Hazard Analysis (PrHA). The Board reviewed PrHA LA-UR-01-2473, *Source Fabrication and Dismantling, Residue Processing and Storage, and Liquid Scintillation Counting Activities*. Section 3.4 of the PrHA addresses the storage of residues and states that the residues include contaminated cheesecloth and glovebox gloves and contain small amounts of Pu-238 (average of 2 grams with a range of 0.2 to 25 grams). This section also states that the residues are stored in a sealed inner metal container, a particulate-filtered heavy gauge plastic bag, and a sealed outer container.

The PrHA addressed radiological contamination and exposure hazards due to dropping of a sealed container, and determined that the risk to the public is below the evaluation guidelines when taking credit for the gloveboxes, building confinement, and the building's HEPA-filtered ventilation. Additionally, the PrHA identified "containers designed with proper integrity to confine their contents" as protective features and CAMs as protective systems.

The Board concluded that the PrHA assumed storage packages were designed with proper integrity to confine their contents and, as a result, did not analyze the risk to workers associated with a package failure. However, the need to design the packages did not flow down into implementing procedures for storage in room 201B.

The HCPs flow down from the PrHA and were intended to identify controls to reduce the residual risks to workers from specific process activities. The following paragraphs outline HCPs that were in place and related to the Pu-238 activities.

NMT-HCP–009 Pu-238 Residue Processing Operations, Nov 2002: This HCP addressed the Pu-238 residue solidification process in PF-4 rooms 206 and GB 203. The HCP identified a radioactive contamination hazard with a low initial risk and minimal residual risk through inventory controls (thermal limit of 500 grams of Pu-238) and procedures.

NMT-HCP-NMT-015 Preparing and Packaging Waste: This HCP applies to waste originator activities that are associated with preparing, packaging, and handling of waste including transuranic waste. This HCP also applies to removing and packaging items from gloveboxes. The HCP identified a radioactive contamination hazard with a low initial risk and minimal residual risk through implementation of procedures.

TA55-HCP-001 TA-55 Vault Operations: This HCP applies to operations in TA-55 vault including packaging, adding or removing packages, and the inventory of items in the vault. The HCP acknowledges that older packages may fail causing a radioactive contamination hazard with a low initial risk and minimal residual risk through installation of CAMs and implementation of procedures.

The Board concluded that NMT-9 did not complete an HCP that specifically addresses the worker hazards associated with storage and handling of packages during inventory activities in room 201B. As such, NMT-9 did not define a limit for the amount of material in the room; they did not define the types of material and chemicals that could be stored in the packages such as cheesecloth and nitric acid; and did not determine the length of time the material could be safely stored without formal surveillances.

The Board also noted that in contrast to the above, the HCP for TA-55 vault operations acknowledged that packages may fail and established controls such as CAMs, packaging requirements, and procedures for conducting the inventories.

The NMT Work Instruction, *WI-021-Nuclear Materials Packaging,* was established in 1998 and applies to packaging, unpacking, shielding, and storing nuclear materials at TA-55, Building PF-4, which may be stored in the vault, shipped to TA-55, or transported through the common areas of PF-4. The procedure does not apply to nuclear material packages that remain inside the same room or laboratory, are packaged as waste that is intended for WIPP, moved between laboratories of the same group without entering a common area, or were packaged before the procedure was implemented on May 1, 1998. The Board concluded that this procedure should have been used for packaging material stored in room 201B since the packages were routinely transported through common areas to be assayed prior to storage.

The procedure identifies the requirements for packaging of containers and identifies three types of packages and requirements for each:

<u>TA-55 approved package</u> – "A nuclear materials packaging technique that is created using containers and supplies on an approved list and that are assembled by using the standard method specified in section 8.2 of the procedure." This package includes an approved inner bag (listed on table A-3 of the procedure), an approved material container (the container that comes in direct contact with nuclear materials listed in Table A-1 of the procedure), and an approved secondary container (listed in Table A-2 of the procedure, and includes stainless steel containers that have filtered lids).

<u>TA-55 non-standard package</u> – "A nuclear materials package that is not packed with TA-55 approved materials. The package is in a safe condition and is not practical or safe to repackage." Section 8.3 further states that the package appears to be in good condition and it is not safe or practical to repack the package in the standard configuration. The procedure does not provide any further definition or criteria for what appears to be a safe condition or criteria for how to review and approve these packages. This section also states that a non-standard package is used for containers packed prior to May 1, 1998 and items intended for WIPP for disposal.

TA-55 unique package – "A nuclear material package that is custom-designed because of the unusual size, shape, or other physical or chemical properties of the nuclear materials to be packaged; not covered by an existing, approved, packaging procedure."

The "Emergency Actions" Section of this procedure states that "if (1) contamination is detected on the outside of the secondary or outer container, (2) a secondary container appears to be bulging, has rust spots, corrosion, and or a loose lid; or (3) a secondary container appears to be severely dented or to have suffered other serious damage that renders it unusable or unsafe, to immediately contact the RCT, over-bag the container, if possible, and immediately notify your supervisor."

Based on the above and interviews, the Board concluded that the requirements of WI-021 applied to the storage activities in room 201B since the containers were moved through common areas to be assayed prior to being stored in room 201B. As such, the inner filtered can, filtered bag, and outer slip top can packaging configuration was a "TA-55 non-standard" configuration since the outer container was not an approved container for storage in the vault.

The Board further concluded that NMT-9 did not identify specific functional requirements or design criteria for determining whether this "non-standard configuration" was safe except for a visual inspection for obvious damage. This was contrary to the PHA that identified "Containers designed with proper integrity to confine their contents" as a preventative feature.

The work control process uses a daily checklist to capture all facility level safety controls and worker safety controls prior to authorizing programmatic work in a specific room. Upon satisfactory completion of the checklist, the room is released for programmatic work. The Room Controller is responsible for completing the checklist. The checklist for rooms 201A, B, C, and D included HSR-1 Daily Operational Checks, glovebox and zone differential pressure readings, and overall housekeeping requirements.

The Board noted that the NMT-9 did not incorporate specific facility and worker hazard controls derived from safety analysis into the room 201B checklist such as "Storage Rack Seismic Restraints" (TSR Design Feature), and surveillances of packages to check for abnormal conditions such as bulging, rust, etc. (PHA and new SAR requirement).

The Board noted there is a large body of information available concerning storage of plutonium oxide and known failure mechanisms such as chemical and radiological decomposition of PVC bags, gas generation, thermal decomposition of cheesecloth, chemical incompatibles of materials, and generation of chlorides and formation of hydrochloric acid. Much of this information was known and disseminated prior to the onset of the current use of room 201B for storage in 1995. The following are a few of the documents that include information of these mechanisms (see Section 3.3 for detailed discussion of these mechanisms):

- DOE/EH 0415, *Summary of Plutonium Working Group Report on ESH Vulnerabilities associated with the Department's Plutonium Storage*, Volume II, Part 3. 1994;
- DNSFB Tech Report #1, *Plutonium Storage Safety at Major Department of Energy Facilities*, 1994;
- DOE-STD-3013, *Criteria for Safe Storage of Plutonium Metals and Oxides,* first published in 1994; and
- LA-12999-MS, *Plutonium Dioxide Storage: Conditions for Preparation and Handling*, 1995.

Additionally, numerous operational events contained information concerning the same mechanisms and the need to properly analyze and package plutonium residues (see Section 3.7).

The Board concluded that NMT was aware of these mechanisms when developing the SAR but failed to thoroughly evaluate all available technical information when conducting the hazards analysis in the SAR, PHA, and subsequent HCPs. As a result of this failure, the Board concluded that NMT did not identify and implement appropriate worker level controls for the storage and handling of Pu-238 residues.

The Board reviewed the new SAR submitted to NNSA LASO for approval in April of 2002. A Pu-238 release from a degraded storage container was addressed in the new SAR and included the same analysis as the 1996 SAR. However, the following statements in the 2002 SAR were not in the 1996 SAR:

- Before personnel remove a container, they examine it and all other containers in that area for deformities. If any deformities or bulges are observed, the worker retrieving the container is required to report the deformity so the container can be bagged and taken to a glovebox for further inspection and possible repacking.

- After a period of time, some containers may show signs of radiolytic-induced deterioration. One such sign is the blackening and embrittlement of the bagout bag. A sign of more serious degradation is corrosion of the inner and outer containers. Monitoring by workers and RCTs helps in detecting any degradation and or breaches of containers.

Section 4.4.5, "Containers for Storage and Transportation of SNM," of the new SAR addresses the safety function and requirements for the containers since they were credited as safety significant controls in Chapter 3. Specifically, the safety function of the containers was to provide primary confinement of potentially dispersible radioactive material and provide resistance to spills should a container be dropped. The associated functional requirements stated that containers used for storage or transportation of SNM at TA-55 must be able to provide primary confinement of potentially dispersible materials and provide resistance to spills should a container be dropped.

The new TSRs incorporate the following Administrative Controls (AC), Design Features (DFs), and In Service Inspections (ISIs) related to preventing and mitigating a release from a degraded storage container:

- Radioactive Material Inventory Program (AC)

- Containers for storage of transportation of SNM (DF-5)

- All SNM containers are to be inspected for signs of wear or degradation (ISI)

The Board believed that the new SAR may have helped mitigate this event since it recognized the technical information available regarding packaging failures and subsequently identified the need for packaging containers as Design Features with specific functional requirements and surveillance requirements for the containers.

The Board concluded that the technical basis for long-term storage of items in room 201B was incomplete since well-documented and known mechanisms for failure of the packages were not fully analyzed in the facility Safety Basis. The Board also concluded that appropriate controls for preventing and mitigating the consequences to workers from a radiological release due to a package failure were not developed and flowed down from the DSA into HCPs and implementing procedures. Furthermore, the Board concluded that NMT-9 had not complied with NMT requirements regarding the use of a non-standard package for storage of plutonium-bearing residues.

3.3 Analysis of Packaging Failure Mechanism

In order to understand the possible failure mechanisms of the packages, the Board conducted a review of previous operational experiences with similar storage of plutonium-bearing materials at several DOE sites. In addition, the Board decided to examine the conditions of the remaining cans in the other cages and on the floor in room 201B. A reentry team composed of Board members and NMT staff accomplished this assignment.

Prior to entering room 201B, the reentry team observed a slip-lid can that showed signs of degradation in a glovebox in room 201. NMT-9 staff stated that the activities in this glovebox used nitric acid, resulting in a caustic environment within the glovebox. The slip-lid can was introduced into this glovebox in June 2003 and had significantly corroded since then, as shown in Exhibit 3-1. In addition, cheesecloth contained in the glovebox appeared to be discolored and was beginning to decompose (Exhibit 3-2).

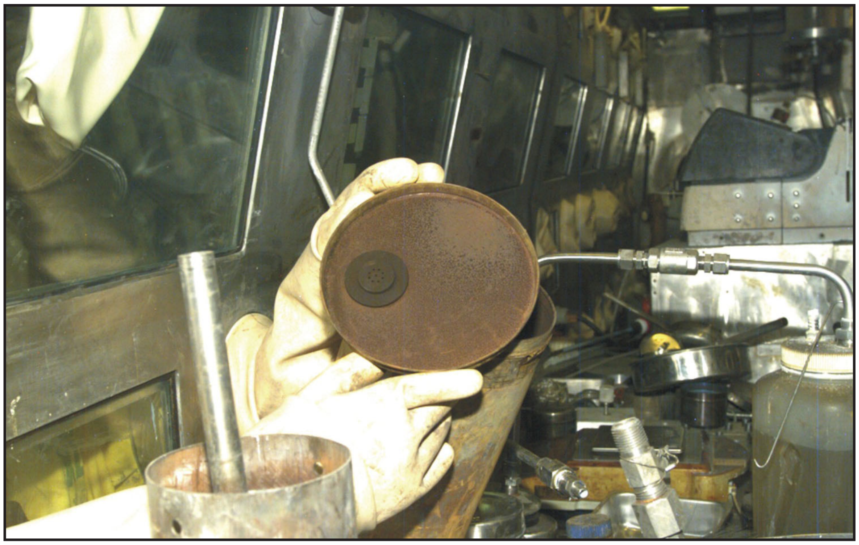

Exhibit 3-1 Acorroding can in a nitric acid glovebox in room 201.

In room 201B, the reentry team found packages sitting in a small cart that had corrosion products flowing down the exterior surfaces of the outer cans (Exhibit 3-3). Several other packages were identified that showed similar indications of corrosion products seeping out around the tape seam (Exhibits 3-4 and 3-5). One package appeared to have corroded all the way through the outer can wall (Exhibit 3-6). A sample was taken of the corrosion products collecting in the cart, as shown in Exhibit 3-3, and it was found to be composed of mainly iron oxide (rust) with some chlorine. The Board noted that most of these packages had been created in the last 10 months, with one being only about 1 month old. Furthermore, the Board noted that these observations are very similar to those recorded for the second of the two events that were evaluated in the 1994 Type C Accident Investigation. None of these packages showed signs of having released any contamination, and so it was apparent that the interior boundaries were still intact.

Additionally, three packages showed signs of physical damage (depressions) on the sides and the lid, as shown in Exhibits 3-7 and 3-8. The Board suspected that the packages might be showing signs of "paneling," a condition where the pressure inside the package was decreasing causing a vacuum (see Section 3.4). The pressure decrease could be formed by the consumption of oxygen and nitrogen in the package's internal atmosphere by chemical reactions. Several DOE published reports identify these reactions. An alternate explanation could be physical damage caused by handling.

Exhibit 3-2 Cheesecloth used in the nitric acid glovebox in room 201.

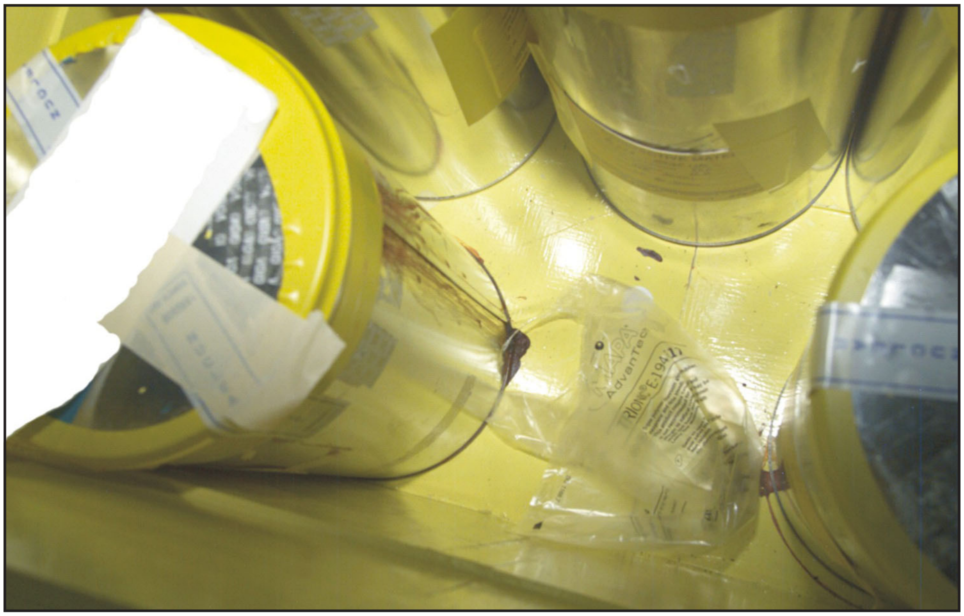

Exhibit 3-3 shows the corrosion products seeping down a package and onto the cart.

Exhibit 3-4 shows a package with apparent corrosion products seeping under the taped lid.

Exhibit 3-5 shows a package with apparent corrosion products seeping down the side of the package.

Exhibit 3-6 shows a package with apparent corrosion induced failure. This package had been created less than two months before this picture was taken.

Exhibit 3-7 shows the side of a suspect "paneled" package.

Exhibit 3-8 shows the lid of a suspect "paneled" package.

The *Plutonium Working Group Report on Environmental, Safety and Health Vulnerabilities Associated with the Department's Plutonium Storage (1994)* describes potential packaging weaknesses and degradation of Pu-238 oxides. The most significant vulnerabilities are radiolysis and chemical reactions. The radiolytic decomposition of plastics by plutonium causes hydrogen generation, which may lead to pressurization of the packages if they are not adequately vented. Plastic bags in contact with plutonium have been observed to fail in less than a year, depending on the type of plastic and its proximity to the plutonium. Regular packaging methods routinely allow air and moisture to enter, resulting in oxidation forming on the container. Plutonium-238 oxide presents an additional vulnerability because the higher rate of helium gas formation due to radioactive decay could increase the pressure buildup. Plutonium oxide is a fine powder, which can easily escape from ruptured packages and disperse into the atmosphere, especially if driven by a pressure difference between the interior of the package and the ambient atmosphere. In addition, Pu-238 particles tend to fractionate due to the high specific activity and the large recoil energy of the decay products, therefore the powder can become finer and more respirable with age.

When plutonium packages are uncharacterized, additional hazards may be present in the containers that could either act as catalysts to the can and bag degradation reactions, or be stimulating additional unknown chemical reactions. For example, a Los Alamos technical report, *Gas Generation over Plutonium Oxides in the 94-1 Shelf-life Surveillance Program, LA-UR-02-0583*, states that the evolution of hydrogen gases from plutonium-bearing residues, inadequately stabilized oxides, and incompatible materials is well known. The report cited the concerns of generation of H_2 gas from adsorbed water, the generation of water in the vapor phase, and the generation of HCl or Cl_2 gases from the radiolysis of chloride-containing materials. The combination of chloride bearing gases and condensed water may generate localized corrosion.

Radiolysis of Plastic and Cloth

$$\text{-}CH_2CH_2CH_2\text{-} + 3O_2(\text{air}) + 2H_2O + \text{alpha-particle energy} \longrightarrow 3\,H_2 + 3\,CO_2$$

(typical hydrocarbon)

Radiolysis of Absorbed Water

$$2H_2O + \text{alpha-particle energy} \longrightarrow 2H_2 + O_2$$

A report from Westinghouse Savannah River Company, *Repackaging Collapsed Plutonium Oxide Containers in FB-Line (U) (1997)*, describes an event where three collapsed cans of Plutonium oxide were discovered while performing routine vault surveillances. The report cites numerous reports from different sites of cans of plutonium metal collapsing during storage, but few involving plutonium oxide.

$$Pu + H_2 \longrightarrow PuH_2$$

$$PuH_2 + N_2 \longrightarrow 2\,PuN + 2\,H_2$$

When sufficient oxygen and nitrogen have reacted to create a large enough vacuum, the can collapses on the sides typically forming three to six faces (referred to as "paneling"). Laboratory studies of Savannah River Site (SRS) food pack cans have shown onset of collapse at under-pressures greater than 2 psi below ambient conditions. The Board identified three cans in room 201B that appeared to be paneled. These cans were inwardly deformed on several sides and uniformly on the can lid. NMT personnel offered an alternate explanation that the containers may have been deformed from rough handling, rather than caused by a vacuum from a chemical reaction. The Board recognizes that the documented studies focus on the PuH_2 and PuN formation from plutonium metal rather than from plutonium oxides, and the material in these packages was believed to be in the oxide form, and of low plutonium quantity. However, the Board believed that the paneling of the cans could be caused by additional chemical reactions involving the chemicals collected with the rags during the packaging of the cans. Regardless of whether the packages were deformed from paneling or rough handling, the Board believes that either action would represent a viable failure mechanism for the packages. Facility procedures require that packages with external defects or severe dents be immediately reported to the RCTs; however, these packages had apparently never been reported.

The DOE Release Fractions Handbook (DOE-HDBK-3010-94) compiled estimates of experimentally derived airborne release fractions for use in accident analyses. For the situation similar to that observed in this accident (venting of pressurized powders at pressures less than 25 psig), the handbook estimates that the fraction of material that would be released would range from 5 x 10^{-5} to 1.7 x 10^{-3}, depending on the pressure. In this accident, the estimated release ranged from 2 to 9 micrograms, and the package contained 13.3 grams of Pu-238. Consequently, the actual fraction released can be estimated as 1.5 – 6.8 x 10^{-7}, which is significantly lower. Therefore, the Board concluded that the quantity of material released in this accident could have been significantly greater, and that there were no barriers in place to prevent a higher consequence. Furthermore, the Board concluded that the consequences of this event could also have been greater if the geometry of the release had been such that the bulk of the material was sprayed into the face of one of the employees rather than towards the floor.

The Board concluded that the chemical reactions observed in the plutonium packages in room 201B are consistent with the radiolysis, gas generation, oxidation, and container failures published in DOE and LANL reports. The Board concluded that all of the failure mechanisms identified during this investigation were recognized phenomenon within the DOE complex, and were known to DOE and LANL before the onset of this storage activity in 1995.

Furthermore, the Board is concerned that there may be other unknown and unexpected additional chemical reactions that could also be occurring in the packages because of the lack of controls on what was placed in the packages. The Board concluded that there were likely to be multiple failure mechanisms in progress within the packages in room 201B, and therefore there was a significant residual risk in the room that needed to be addressed.

The Board presented the above concerns to the Appointing Official, who directed that the responsible LANL associate laboratory director for the facility be informed. As a result, LANL curtailed all Pu-238 process operations that generated glovebox residues stored in slip-lid over-pack containers until the can failure mechanisms in room 201B were fully understood and controls were established to protect the workers.

3.4 Design, Procurement and Quality Assurance of Packaging Materials

The Board reviewed the various design, specifications, and procurement controls for the packaging components used in the process to handle the plutonium. The Board also reviewed the procurement documentation of the associated materials. These packages fall outside the purview of DOE Standard 3013, and the design requirements for such materials are not identified by any alternative standard. The packaging components consisted of a PVC bag, two tin cans, vinyl tape, and particulate filters.

The facility began using PVC bags in 1982, and the same or similar are still in use. The procurement specifications include the bag materials, dimensions, construction, strengths, workmanship, leak testing, and packaging. More recent procurements (circa 1996) of these bags have included specifications for conformance with the appropriate industry standard. Based on LANL's specifications, the particulate filter supplier either procured the bags from various manufacturers or constructed them in-house, and then installed the filters before shipping the completed bag assembly to LANL. After LANL received the bags, they were stored in the TA-55 warehouse until requested by the working group. There are no specific storage or shelf-life requirements established for these components when they are in the warehouse.

The specification and qualification requirements for the tin metal cans were reviewed. The particulate filter supplier, in a manner similar to the PVC bags, procures the cans and installs the filters, although the cans normally come from a sole supplier source. After document review and discussions with the can supplier, it was determined that the cans were procured without specifications, testing requirements or standards. The Board learned from the can vendor that these cans are intended only for the storage of "solid" lightweight materials.

The cans are constructed of commercial grade tin [1/8-inch thick (iron base with a tin coating). The can supplier stated that the seams and lid are crimped and rolled under 20 psi @ 1000rpm. The combination of the pressure and speed will result in a brazing of the metals where joined to induce a seam. However, the supplier noted that the seam is not to be considered air tight or capable of containing any fluids. The can supplier further stated that no testing is done or required on this type of can, and as such, it is considered not to have stated properties of shear, compression or pressure resistance/strengths (tensile).

The particulate filter supplier installs the filters on both the cans and the bags. The earlier (circa 1982) filter installed on the bags specified only using a "glue" to seal and fix the filter to the bags. Later documentation (circa 1996) specifies RTV 732 and RTV 736 to affix the filters to the bags.

The filter is constructed of two pieces, which are joined to form one filter between a medium (the can and/or the bag). The housing consists of a high density polyethylene with closed cell neoprene washers on either side to house a carbon particulate filter in the center. A seal and housing is used when the filter is used on the PVC bag. The filter material is carbon composite approximately ¼-in thick and 2-in in diameter. The supplier's carbon filter testing resulted in 99.97% removal of 0.3 to 0.5 micron particles using appropriate testing procedures at specified differential pressure and flow rates.

Vinyl (PVC) tape is used to seal the bag and to restrain both the inner and outer can lids to the can housing. Tape may also be applied around the bag to compress the bag against the can as to prevent expansion of the excess materials, although this was not observed in the packages disassembled during this investigation.

The Board reviewed the quality assurance (QA) requirements in acquisition of these materials, and compared the NMT QA requirements with DOE QA standards. NMT had a QA program during the initial procurement of these materials and has also recently improved the QA requirements to meet the current DOE procurement and QA requirements.

The Board found, through numerous interviews of NMT-9 personnel, that NMT-9 considered the outer cans to be "breathable," which was based upon the design of the can as being a "breathable food pack can." The packing requirements for the packages prescribed that a particulate filter be placed on both the bag and the inner can to allow the gas generation to vent from the inner can filter, then through the bag filter, and then finally escape through the breathable outer can. However, the use of the tape on the outer can lid reduced the can's ability to "breathe." Also, the Board found that the corrosion inside the can further limited the can's ability to breathe through the seams and around the lid. As noted in section 3.2, NMT-9 did not perform a hazard analysis, which could have identified the known potential problems associated with the use of this can and the methods employed in this process. NMT-9 failed to recognize that both the tape and rust could act as a seal, prohibiting the venting of gas generation. NMT-9 also failed to recognize and or analyze the impact of chemical interactions of the contained residues on the packaging materials.

In reviewing the facility radiation protection procedures, the Board noted a requirement for triple containment of dispersible plutonium. In meeting this requirement, NMT-9 did not consider residual contamination on the outside of the inner can from its presence in a contaminated glovebox. NMT-9 considered the inner can to be the first containment barrier even though there could be a significant amount of Pu-238 contamination outside the inner can. In contrast, the TA-55 Authorization Basis considers the slip-lid containers as a confinement boundary and not a containment barrier. Therefore, the number of containment layers between worker and plutonium in a slip-lid container is only the plastic bag. However, the Pu-238 contamination on the outside of the inner can comes in direct contact with the PCV bag and accelerates its degradation.

Numerous existing documents (discussed in Section 3.3) demonstrate that various gases, including hydrogen, chlorine, and helium, are generated from radiolysis, chemical, and exothermic reactions. These studies show that after long storage times the quantity of gas generated could result in pressures of several order of magnitudes above atmospheric pressure if not vented properly. These results were from calculations for materials that had gone through "stabilization" to reduce gas generation. Given the estimates from these historical reports, it is likely that the decomposition of the materials in the packages stored in room 201B could increase the internal pressure in the package if it were sealed. Interviews with facility staff indicated that they were aware of, and in some cases had been involved with some of these studies.

The Board's review of the NMT QA program found that all related documentation was satisfactorily conducted and executed within the NMT QA requirements, and was not a contributing factor of this event, since no design specifications for the cans existed. The Board also noted that there were no requirements placed on the storage of bags in the warehouse. However, the Board did not consider the storage of the bags in the warehouse as a failure mechanism in this accident.

The Board determined that despite numerous articles, documentation, and direct knowledge of the effects resulting from incompatibility of material, radiolysis, and chemical reactions, NMT-9 continued to package the Pu-238 materials in the same fashion from 1995 to the present. This is in direct contrast to the Pu-239 operations at TA-55, which have modified procedures and practices to incorporate those lessons learned. Furthermore, NMT-9 did not consider known effects of placing the vinyl tape circumferentially over the lid of the outer can, in that the tape would limit the cans' ability to breathe. The Board found that facility procedures required that tape used to secure the lid be placed in an "X" type pattern to prevent a seal.

The Board concluded that NMT-9 did not perform a design of the packaging to be used in this application. NMT-9 had not conducted a hazard analysis concerning the use of the bags or cans in the process environment, nor did they recognize the consequences of placing tape on the can lids and creating a possible seal. NMT-9 did not consider chemical incompatibility of materials used. The Board also concluded that NMT-9 did not take corrective actions or modify procedures to prohibit use of such packages despite direct and indirect knowledge of historical problems with such use.

3.5 Work Controls

Work control requirements at TA-55 flow down from various Laboratory Implementing Requirements (LIR) into specific NMT administrative procedures. The TA-55 Facility Operations Manager (OM) is ultimately responsible for safe facility operations through the work control process. Formal Facility Operations Management/Tenant Agreements have been documented between facility operations management and tenant organizations to establish safety interfaces, roles, responsibilities, and authorities between the facility operations management and facility occupants/tenants. There is a specific agreement between OM and NMT-9 as a tenant organization.

The Facility Operations Group (FMU-7) manages the physical plant and facilities for the TA-55 OM, which generally includes maintaining, modifying, upgrading, and repairing facility systems. Specific work control requirements are contained in a NMT Division Administrative Procedure.

Tenants, including NMT-9, are responsible for "process, experimental, and operational equipment; operational processes; and interior space that is occupied by the tenant and other areas to a given facility or operation." This includes compliance with established change control and unreviewed safety question determination (USQD) processes. It is the responsibility of all groups to ensure all operations and work activities are conducted with the bounds of Documented Safety Analyses. Tenant work activities are to be conducted in accordance with approved HCPs, Short Duration Hazard Controls Plans (SD-HCPs), and RWPs within the bounds of the Documented Safety Analyses including any Technical Safety Requirements, limiting conditions of operations, process hazards analyses, and/or Design Features for Safety. Specific procedures and requirements exist for each of the above and require hazard assessments and controls.

An exclusion in NMT-AP-007 states "work that has **no hazards other than radiological** is performed under the auspices of a radiation work permit." This exclusion is allowed per LIR402-700-01.

On the day of the accident, two workers were conducting a "pre-inventory" activity in room 201B in preparation for an upcoming required bi-monthly physical inventory. The purpose of this activity was to verify that packages of Pu-238 residues in the room were properly labeled and sealed per nuclear material accountability and control (NMC&A) labeling requirements. During routine bi-monthly physical inventory activities, a random set of items is normally pre-selected by NMC&A personnel for subsequent auditing during the physical inventory. However, due to previous problems complying with statistical inventory limits during bi-monthly inventories, NMT had initiated these "pre-inventory" checks prior to the scheduled inventories in an effort to improve compliance. Other inventory issues also required each individual package to be checked. In order to accomplish this, TIDs had to be removed from cage doors, the doors opened, packages individually removed from the cages, checked and replaced back into the cage. This resulted in increased handling of all packages in room 201B beyond previously expected levels.

The only work control document in place during this activity was a standing RWP for entry into a high radiation area behind the shield. This RWP had been approved in January 2003 and was effective until December 2003. No hazard control plan or procedure was referenced on the RWP. In addition, no HCP was ever completed for storage activities in room 201B. The room was posted as both a radiological buffer area and a high radiation area behind radiological shielding at the cages containing cans. Nuclear Material Control and Accountability procedures for conducting physical inventories existed but were not being used at the time since this was a "pre-inventory" check. The RWP stated specifically that only radiological hazards were present. Although radiological hazards certainly were present in room 201B, industrial health and safety hazards also existed involving the moving of heavy shielding and cages, the removal and re-installation of seismic restraints, and the removal and manipulation of Pu-238 storage packages. The RWP specified that only routine MC&A tasks were to be performed.

Other RWPs were reviewed for activities being conducted in room 201, adjacent to room 201B. One was written for the replacement of windows on gloveboxes and another was written for installation and retrofit work on gloveboxes including electrical work. The section asking whether or not non-radiological work was to be performed was not completed on either, and no hazard control plan was referenced on either. Both of these activities included non-radiological work activities with potential hazards.

A facility Design Feature was identified in the SAR requiring seismic restraints on the cages in room 201B. The pre-inventory activity being conducted required moving shielding away from the front of cages and the removal of restraints from the cage(s) in order to access cage doors. A hold point was identified in the RWP requiring notification of a RCT prior to moving the shielding; however, no procedure or work instructions existed for removal and proper re-installation of the restraints from the cages. In addition, no surveillance procedure was in place ensuring periodic surveillance of the restraints and, no formal or informal notifications were made (or required) to the Facility Operations Group or Operations Center regarding the facility being outside the approved safety envelope. Further, during the Accident Investigation, a Board member discovered the restraints on cage B to be broken and inoperable, and the restraints on cage A to be improperly installed. The amount of time the restraints were in this condition was indeterminate.

Section 3.3 discusses details of the failure mechanisms of the Pu-238 storage containers. These mechanisms have been documented in numerous publications, documents, and recommendations well prior to this event. Also, the 1994 Type C investigation of two events involving Pu-238 contaminated cheesecloth identified several findings directly applicable to the current event that could have prevented this current event. This investigation and the LANL response to it are discussed further in Section 3.7.1. As noted in Section 3.3, the Type C Board found that "The current storage of waste cans containing plutonium-238 contaminated cheesecloth in room 201B poses an unevaluated hazard." This prompted LANL to conduct an evaluation in the 1996 SAR that concluded that the risk to the public and environment were bounded by other accidents, but there was recognition that the condition represented a potential hazard to the workers. However, LANL has not developed a HCP for the activities in room 201B. The lessons learned from that investigation would have been available for inclusion into a hazard evaluation of storage activities in room 201B had one ever been completed. In addition, only a few months before the accident being investigated here, NMT-9 personnel had discovered a package during recent processing activities where the bottom of the inner can had rusted out completely, in the same manner as the inner can that failed in this event. However, only limited corrective actions were taken, and nothing regarding the corrective actions was documented.

The Board concluded that work controls requirements were not adequately implemented to identify and control hazards associated with storage activities in room 201B. The Board concluded work activities that included non-radiological hazards were being conducted using only RWPs. This is inconsistent with the intent of Laboratory Implementing Requirement and NMT procedure exclusions stating that work that has **no hazards other than radiological** is performed under the auspices of a radiation work permit.

The Board concluded that NMT failed to recognize or implement work control requirements to ensure proper removal, re-installation, and surveillance of a Design Feature for Safety. This resulted in this feature being inoperable and the facility being outside the authorized safety basis for an undetermined amount of time.

The Board concluded that the failure to recognize and incorporate lessons learned from readily available information and previous significant and relevant incidents into current work controls practices represents a significant weakness.

3.6 Performance of Work

The UC/DOE Contract requires the performance of operations be in compliance with DOE Order 5480.19, *Conduct of Operations Requirements for DOE Facilities*. The Order outlines the requirements that authorize work, identify risks to operations, and describe the development and implementation of controls needed to perform work safely. Hazard controls must be identified and implemented before commencing work. The Order emphasizes designing the work or controls to reduce or eliminate the hazards, and to prevent accidents and unplanned releases and exposures. The Laboratory Performance Requirement (LPR) for the implementation of Conduct of Operations is a mandatory requirement for laboratory processes for accepting and performing work. The performance criteria of the LPR directly correlate and implement the conduct of operations chapters of DOE Order 5480.19.

Because the pre-inventory activity was programmatic work rather than facility work, it was not scheduled on the Plan of the Day or Plan of the Week, although the activity was being conducted in a High Radiation Area and required circumvention of a facility Design Feature for Safety. As stated in Section 3.2, a hazard analysis was not performed and a Hazard Control Plan was not developed for the room or the activity.

During the conduct of this investigation, the Board noted a variety of discrepancies between the manner in which the work related to this event was conducted and LANL's requirements and procedures that were established to govern that work. All of these discrepancies have been discussed elsewhere in this report, and so they will only be noted here:

- Evacuation of E1 and E2 from room 201B to room 201A, and subsequent use of room 201A as response point was contrary to site training, which directs that such evacuations be to the corridor.
- The actions of the Operations Center were inconsistent with the CAM Alarm Response Instruction; the Operations Center did not log all data from CAM alarm, did not announce all CAM alarms, and did not follow the contact list to ensure that the appropriate supervisors were notified.
- E1 and E2 were only wearing one pair of gloves, which is contrary to the RWP.
- The responsible RCT did not provide continuous coverage during the movement of the shielding, which is contrary to the RWP.
- Storage of Pu-238 packages on the floor was not consistent with the SAR analysis, which assumed storage in cages only.
- Seismic restraints were TSR-level controls, but their removal and replacement was not addressed in procedures.

- Some seismic restraints were found by the Board to be broken or missing for an unknown period of time, a condition that had not been identified or addressed by NMT-9.

- There is a significant contrast between the HCP, load limits, packaging criteria, and procedures for the Vault and the lack of an HCP, limits, and packaging criteria, and uncertain procedures for room 201B.

- NMT-9 did not comply with NMT requirements for the design and approval of non-standard packages for storage of residues.

- Procedures required that packages observed with external defects were to be immediately reported to RCTs for bagging and moving to a glovebox for evaluation. However, the Board found several packages in room 201B with obvious external defects that were never addressed.

- Package lids were taped circumferentially, contrary to procedures that specified a cross-taping of lids to allow them "to remain unsealed". (Actually, even some of the procedures contradicted each other on this point, adding to the confusion.)

- It was not clear if the packages complied with the radiation protection procedure, which required triple containment of powdered material. There were three boundaries, but contamination was known (and assumed) to be present on exterior of the first layer, the third layer did not represent a sealed boundary, and failure of at least one of the three barriers had been frequently observed in other packages. (The word "containment" was not defined in the procedure, so it is not clear what the expectation meant.)

- The Board concluded that the relevant RWP was used as a work control document beyond the intended scope stated in the radiation protection procedure.

- Facility personnel exhibited confusion over the intent of requirements on the RWPs, such as "continuous coverage" and "taped openings". The RWP for room 201B was established for controlling a high radiation area, but the controls focused primarily on contamination control and not external exposure control.

- E2 had not signed in on RWP, therefore had not had a pre-job brief. It was not clear if E1 was current, although E1 had signed in January 2003. The procedure requires resigning (and consequently a new pre-job brief) if the work is conducted intermittently (periodicity of greater than 30 calendar days).

- The Board determined that other personnel who had previously conducted inventories in the room had also not signed in on the RWP.

- The Board encountered an inconsistent application of requirements between NMT-9 and other NMT groups, for example NMT's ban on the use of cheesecloth in areas with nitric acid was implemented in the Pu-239 areas but not the Pu-238 area.

- Facility personnel exhibited confusion over the facility's "two man rule". Was this for safeguards and security or for safety? When is it to be applied? Were E1 and E2 in compliance or not? This requirement was not formalized and therefore workers were not clear of the requirements or expectations.

- NMT-9 procedures discuss use of ethanol and distilled water to clean gloveboxes. There was no mention or analysis for use of the commercial cleaner that was commonly used.

- The facility staff exhibited confusion over which procedures actually applied for the packaging of these materials.

- Room 201B had not undergone an ALARA evaluation, even though it is the only non-intermittent accessible high radiation area in PF-4. The vault has received a comprehensive ALARA evaluation. E1 and E2 attempted to apply ALARA concepts to their own activity, but this practice was informal and ineffective.

Over the past three years, LANL has been subjected to numerous event-driven internal and external investigations of worker safety issues. There has been a significant increase of notable events. Cited below are examples of these investigated events:

- DOE Type A Accident Investigation of the Pu-238 Multiple Intake Event at TA-55;
- LANL Accident Investigation of a Chlorine Dioxide Explosion;
- LANL Accident Investigation of the TA-16 Ladder Fall with Compound Fracture;
- LANL Accident Investigation of the DX Division Flash Burn Injury;
- LANL occurrence investigation of Hexane Flash to the Face;
- LANL Accident Investigation of Acid Splash into the Eyes of a Scientist;
- LANL occurrence investigation of Work in High Voltage Switch Gear without a Hazard Control Plan (HCP);
- LANL Investigation of Violation of Procedure Results in Near Miss to a Severe Injury from Electric Shock;
- LANL Investigation of Unauthorized Work Results in a Contaminated Pipe in an Uncontrolled Area;
- LANL Investigation of Intermittent Roofing Work Conducted During Same Time Frame as Radiography Operations;
- Three DOE Price-Anderson Enforcement Actions – all of which included issues concerning the performance of work within TA-55.

Additionally, in July of this year, a DOE Office of Price-Anderson Enforcement Letter was issued to LANL stating that nuclear safety at LANL "continues to demonstrate a negative performance trend … based on numerous recent events involving both nuclear safety and radiological controls." Specifically in relation to events at TA-55, the letter states that "[The Office of Enforcement] is concerned that the frequent and repetitive nature of these events is indicative of both quality improvement and programmatic work control issues."

The Board concluded that NMT placed an over-reliance on worker-applied knowledge when performing work. Also, the Board concluded that NMT had not consistently applied the ALARA processes to its operations in PF-4. Furthermore, the Board concluded that RCT staff had failed to recognize that the RWP requirement for continuous coverage was based on radiation exposure rather than contamination control.

The Board is concerned with LANL's organizational safety culture. The Board believes that there is complacency regarding safety among the workers and management at LANL. With regard to this specific accident investigation, the workers' and managers' failed to respect the hazards and failed to comply with the controls. The Board believes that LANL has not been successful at making timely changes or at effectively preventing recurrence of safety insults or degradation. The facility's qualitative evaluation of the worker safety for a situation such as this accident expected a dose or uptake to the worker that could well exceed the DOE's annual limits. However, LANL and NMT accepted this risk without understanding the magnitude of the consequences or the probability of the occurrence.

The Board concluded that the conduct of operations was not effective in managing the entry into room 201B for the activities being performed at the time of the accident. The Board concluded that LANL's safety culture has evolved to one of complacency towards safety such that workers and managers fail to respect the hazards present in the workplace, and accept risks to workers without understanding the magnitude of those risks.

3.7 Feedback and Improvement

3.7.1 The LANL Lessons Learned Program

The Board reviewed numerous related documents, including a DOE Headquarters' assessment, DNFSB Recommendations, accident investigations, occurrence reports, technical literature and analyses, and a LANL regulatory permit. As a result of the Board's evaluation, it was clear that NMT missed many opportunities to recognize potential storage package problems and associated risks and hazards from readily available sources. Many of these analyses and sources were available from within the NMT organization itself. This section reviews the large body of information and data from analyses performed at LANL that was not effectively utilized throughout the NMT organization. The following is a summary of related documents.

DOE Safety Information Letter: In November 1993, a release of radioactive contamination occurred as a vessel containing a kilogram-sized quantity of plutonium metal was being removed from vault storage at LANL. As a result of this event, DOE Defense Programs issued a Safety Information Letter. The bagged-out vessel was placed in a steel storage can. The slip-lid closure of this can was covered with layers of plastic tape. The incident occurred as the package was being handled. The bagging material was found to be severely embrittled and deteriorated, and one end of the inner welded tube had been ripped open as a result of massive oxide formation in the tube. Depending on the size of openings in the inner vessel, pumping from changes in atmospheric pressure and radiolysis could continue for a five- to ten-year period during which no mass change would be observed and the storage configuration would appear to be stable. The initial stage would terminate when the embrittled bag fails and the inner container is exposed to the oxygen-containing atmosphere in the outer container. Prediction of the rupture condition for both the inner and outer vessels would be complicated by deposition of loose oxide at the bottoms of those vessels as oxidation proceeds. This concentration of products would promote preferential rupture at the bottom of the storage package and make the prediction of package failure very uncertain. Remediation actions were recommended. Specifically, packages identified as having a potential failure problem were to be repackaged, placed in a secondary container with a certified closure or moved to an inert atmosphere. If a problem container was to be opened, adequate precautions should be taken to prevent ignition of pyrophoric materials (e.g., hydride) that might be present.

EH Vulnerability Assessment: A Plutonium Working Group on Environment, Safety, and Health Vulnerabilities Associated with the Department's Plutonium Storage performed a review at LANL in 1994. The Working Group Assessment Team (WGAT) identified in their report a vulnerability concerning worker exposures. The report stated that LANL knew what packages were most vulnerable to corrosion and planned to process and repackage those materials contingent on the availability of personnel and funding. At the time of the report, LANL production commitments to provide fuel for radioisotope thermoelectric generators for NASA's Cassini mission were specifically funded and took priority over repackaging. Concerns about package integrity, the crowdedness of the vault, and impact on the safety of frequent inspections, led the WGAT to identify several vulnerabilities, one specifically similar to this accident investigation, WGAT-TA-55-2, *Corroded Container Of Plutonium Residue Fails During Handling At TA-55 Vault*. The report stated that segregating materials in the vault to reduce handling could reduce vulnerabilities. The report stated the need to identify those packages with the highest likelihood of degradation and require workers to wear respirators when handling packages in the vault. The assessment identified that alpha radiation from the plutonium would irradiate and decompose the plastic bag. The plastic bag could leak and the corrosive residue come into direct contact with the outer slip-top can. Subsequently, when the package is handled a leak could occur. In the worst case, the bottom of the can would corrode away and the contents could spill out when handled. This vulnerability could lead to bodily contamination and worker uptake, primarily through inhalation.

DNFSB Recommendations 1994-1: In 1994, the DNFSB issued Recommendation 94-1, *Improved Schedule for Remediation of the Defense Nuclear Complex*, and associated with it they issued DNFSB/TECH-1, *Plutonium Storage Safety at Major Department of Energy Facilities*. These documents addressed the hazards associated with packaging and storage of plutonium-bearing materials. The Recommendation focused on efforts required to stabilize and safely store plutonium-bearing materials that were in excess of national security requirements. Even though DNFSB Recommendation 94-1 did not explicitly cover the Pu-238 that is stored in room 201B due to the limited scope of the recommendation, the hazards portrayed in the recommendation were directly applicable to the packaging that are now being utilized in room 201B. Appendix B of DNFSB/TECH-1 presented analyses of adverse interactions of stored plutonium with its surroundings. These analyses discussed physical and chemical reactions known to affect plutonium oxide in storage, including several failure mechanisms that the Board found to be relevant to this accident (discussed in Section 3.3 of this report).

DNFSB issued Recommendation 2000-1, In 2000 the DNFSB issued Recommendation 2000-1, *Stabilization and Storage of Nuclear Materials*: This Recommendation reiterated the hazards associated with the packaging and storage of plutonium-bearing materials that were documented in 94-1 and expanded the scope to include programmatic materials similar to the residues that were being stored in room 201B.

The DOE/NNSA and LANL responses to recommendations 94-1 and 2000-1 underwent numerous revisions. The first LANL response to DNFSB Recommendation 2000-1 that was approved by DOE is the May 2003 *Los Alamos National Laboratory Materials Stabilization Project Execution Plan* (LMSP PEP). The plan contained detailed schedules for programmatic repacking and the stabilization of LANL inventory, however, the packages in room 201B were not included. The plan focused on the material stored in the TA-55 vault and did not include packages stored by programs on the floor of TA-55 (e.g., room 201B) because they were considered dynamic and/or transient, based on the assumption that they were in use for programmatic purposes. The plan further states: "There are also programmatic items that currently reside at TA-18, TA-35, TA-48, TA-53, TA-21, and TA-54 which need to be inspected and/or repackaged to meet the Interim Criteria." The plan also states that there are non TA-55 excess items at TA-18, TA-35, TA-48, TA-53, TA-21, and TA-54 that "are generally low mass items, or items which are likely already in a safe storage form, but need to be inspected in order to verify. These items are also generally relatively low in terms of risk prioritization, and will most likely be scheduled for disposition after 2010."

DOE Standard 3013: DOE Standard 3013, *Criteria for Safe Storage of Plutonium Metals and Oxides,* was first published in December 1994, and incorporated into the UC-DOE Contract in October 1997. This Standard was updated and is now DOE-STD-3013-2000. The Standard established requirements for stabilizing oxides; for design, construction, and testing of storage containers; and for container load limits. The Standard also established safety-related requirements for the packaging process, inspection and surveillance requirements, and quality assurance and record keeping requirements. Storage of plutonium-bearing materials must comply with existing MC&A, safeguards and security, and audit and surveillance directives that rely on nondestructive assays as a technique for validation. The Standard does not restrict the isotopic mass content of Pu-238, but relies instead on controlling the heat generation in the package to a 19-watt limit. A sealed container design was specified, rather than a container designed with a gas filter. This was due to a concern that filters allow the entry of moist air which could interact with salts and other impurities contained in the stored materials. Furthermore, if the containers were not oriented or handled properly, stored powder could plug the filters and eventually "blow out" causing at a minimum a local spread of contamination. The Standard required that the material to be stored be stabilized to eliminate plastics, hydrogenous compounds, and other organic materials, because radiolysis and thermolysis of these organic materials produce combustible and corrosive gases and increase pressure within sealed containers.

LANL RCRA Emergency Permit: In May of 1994, the New Mexico Environment Department issued a US DOE/LANL Resource Conservation and Recovery Act (RCRA) Emergency Permit NM0890010515-EP1, *Thermal Decomposition of Nitrated Cheesecloth*. The LANL permit stated "the emergency permit is necessary since the continued storage of the nitrated cheesecloth presents an imminent and substantial endangerment to human health and the environment."

LANL Type C Accident Investigation Board Report: In October and November of 1994, two incidents involving the thermal decomposition and inadvertent burning of Pu-238 contaminated cheesecloth occurred at the Plutonium Processing Facility (TA-55) in building PF-4. Both incidents involved NMT-9 operations in the 200 Wing. After the second event occurred, LANL chartered a Type C Accident Investigation Board, which was in accordance with the DOE Orders in effect at that time.

The first incident was the discovery of a polyethylene bottle that had melted to the side of a can that contained cheesecloth contaminated with Pu-238 in a glovebox. The can contained approximately 30 grams of Pu-238. All the cheesecloth in the can had thermally decomposed. The initial occurrence investigation into this event concluded that the direct cause was that a vented lid had not been placed on the can containing the rags. A contributing cause was the high loading of Pu-238 in the cheesecloth. The root causes of the event were that:

(1) No procedure existed for addressing the packaging of rags and combustible materials containing Pu-238 oxide.

(2) Procedures did not exist to address the operational limit for the amount of Pu-238 oxide that could be safely loaded into each can of cheesecloth nor did NMT-9 address procedure steps for decontaminating gloveboxes. The use of alcohol-wetted cheesecloth for cleaning the gloveboxes was not addressed in any procedures.

(3) Room 201B was originally a material management room, however the room was changed to a temporary storage and waste work-off area when the need arose to store packages of cheesecloth with Pu-238 contamination. The use of room 201B was not addressed in any procedures. There were no operational loading limits for Pu-238 material stored in room 201B. There were no procedures for monitoring the amount of Pu-238 that could accumulate in room 201B. There were no procedures for routine inspection of the stored packages in room 201B.

(4) NMT did not have an overall waste management plan for dealing with the cheesecloth loaded with Pu-238 oxide.

The second incident occurred when concerns from the first event prompted an inspection of the packages containing Pu-238 contaminated cheesecloth stored in room 201B. One of the cans appeared to have a brown substance leaking down the side of its exterior (the written description suggests that this was very similar to the packages shown in Exhibits 3-3 to 3-6). The suspect can was placed in a glovebox for examination. After opening the outer can, the bag-out bag, and the inner can, the cheesecloth was found to be damp, and was spread out to dry in an air-glovebox. Within five minutes some of the cheesecloth began to smoke and flames were also observed on a piece of cheesecloth that had been difficult to spread. The initial review of this event concluded that the direct cause was that there were no procedures to address actions to take with abnormal packages of rags. A contributing cause was the high loading of Pu-238 in the cheesecloth caused by an increased wipe down of gloveboxes and process equipment. A second contributing cause was that the two options available for treating or disposing of Pu-238 contaminated cheesecloth were not considered for the packages containing amounts of Pu-238 greater than 2 grams. The lesson learned was that Pu-238 is a heat-generating radionuclide, and combustible materials contaminated with Pu-238 need only have a supply of oxygen to support combustion.

The cause of both incidents was the combination of sufficient quantities of Pu-238 to cause direct ignition of the cheesecloth and the availability of oxygen to sustain combustion of the cheesecloth. Both cans contained more than 20 grams of Pu-238. After consideration of both events, the Type C Board determined six findings, four concerns, and six Judgment of Needs, as follows:

<u>Type C Investigation Findings</u>

- ❑ There are no established procedures for handling and packaging plutonium-238 contaminated cheesecloth.

- ❑ No approved disposition plan existed for plutonium-238 contaminated cheesecloth.
- ❑ The documented procedure for evaluating USQD was not followed.
- ❑ The current storage of waste cans containing plutonium-238 contaminated cheesecloth in room 201B poses an unevaluated potential hazard.
- ❑ NMT-9 personnel have no documented procedures for cleaning the interior of glove boxes and process equipment with cheesecloth and ethanol.
- ❑ NMT-9 has no SOP defining the use of ethanol in glove boxes.

<u>Type C Investigation Concerns</u>

- ❑ Operational staff should review procedures for controlling plutonium-238 dust.
- ❑ A means of extinguishing small fires in glove boxes containing plutonium-238 needs to be developed.
- ❑ The use of ethanol as a cleaning agent needs to be evaluated.
- ❑ NMT does not operate under a waste management plan that specifically addresses management of plutonium-238 contaminated waste.

<u>Type C Investigation Judgment of Needs</u>

- ❑ Inspect or analyze cheesecloth as necessary to obviate introduction of foreign material to the glove box.
- ❑ Limit quantity of plutonium-238 in each can.
- ❑ Limit quantity of combustible material in each glove box.
- ❑ Process the backlog of cans stored in room 201B on a reasonable yet expedited schedule. In the meantime, maintain spatial separation of cans as recommended by Fire Protection.
- ❑ Develop a written procedure for decontaminating plutonium-238 glove boxes, which will aid in accomplishing items 2 and 3 above. This may involve improved methods of decontamination and dust control at the source of generation.
- ❑ Develop training sessions on these procedures which will inform operators of:
  - Plutonium-238 as a fire initiator.
  - Combustibility of rags and any other materials coming in contact with plutonium-238.
  - Waste minimization.
  - Occurrence reporting.

The Board requested the NMT Corrective Action Plan and verification of actions completed resulting from the Type C Accident Investigation. NMT could not retrieve a comprehensive Corrective Action Plan for the Type C, but the Board did find evidence that most of the issues identified had been addressed. However, the Board concluded that there are several similarities between the issues identified by the Type C Board and this current investigation, suggesting that the actions taken were not effective in correcting the issues. Specifically, the Board noted the following:

- ❑ As a result of the recommended evaluation conducted in the 1996 SAR, the load limit for room 201B was eliminated, rather than establishing a value appropriate to the storage of Pu-238;
- ❑ As noted in section 3.2, the Board has concluded that the storage of Pu-238 residues in room 201B still represents an unevaluated potential hazard;
- ❑ Procedures do exist for the use of ethanol and distilled water for cleaning gloveboxes, but ethanol is no longer in general use; rather, the facility uses a commercially

available cleaning solution that is not addressed by the procedure;

- There is no evidence that a limit was placed on the quantity of Pu-238 in each can;

- There is no evidence that a limit on combustible materials in the gloveboxes was established, only a procedural caution to minimize the quantities to that deemed necessary for a 48 hour supply;

- It appears that the backlog of packages in room 201B noted by the Type C Board may have been processed, but then the backlog began to develop again within a year;

- There is evidence of a roughly five year effort to establish a disposition path for this material, but during that period the backlog continued to grow; and

- There is no evidence that the facility resolved the original questions that led to the second of the two events resulting in the Type C investigation; that is, what was the brown material seeping out of the package and what implications did it have for the storage of residues in room 201B?

Occurrence Reports: A review of LANL reports entered into DOE's Occurrence Reporting and Processing System (ORPS) revealed another event that was similar to this accident. In occurrence ALO-LA-LANL-TA55-1993-0004, *Personnel Skin Contamination/ Loss of Control of Radioactive Material*, the contributing cause was that a sub-oxide or hydride residue was created by a transuranic metal being stored for nearly ten years in an oxygen-deficient atmosphere inside a plastic bag, which was contained in a lead-lined container. The root cause was failure to perform an adequate hazard analysis prior to the operation. The lesson learned was that the proper storage of nuclear material as metal is crucial for long-term storage greater than one year. The presence of hydrocarbons (i.e., plastics) in contact with the nuclear material metal during storage is undesirable from the standpoint of radiolytic decay products.

LANL Publications: In 1994, NMT-9 personnel were involved in a combustible gas generation analysis for the purposes of analyzing disposition of waste to WIPP. However, when the Board requested the document, NMT was unable to provide the report or any resulting information.

LA-UR-99-2896, *Summary of Plutonium Oxide and Metal Storage Package Failures:* In 1999, LANL published this report reviewing over 25 plutonium container failures. Failures were documented at Lawrence Livermore National Laboratory (LLNL), LANL, the Plutonium Finishing Plant (PFP) at Hanford, the Rocky Flats Environmental Technology Site (RFETS), and the Savannah River Site (SRS). Two primary failure modes were identified: (1) metal oxidation due to non-airtight packages; and (2) gas pressurization from radiolytic and thermal degradation of inadequately stabilized materials. The largest number of package failures involved storage of plutonium metal in containers that were not airtight. The in-leakage of air led to oxidation of the metal to the dioxide, accompanied by a large increase in Plutonium material volume that then caused mechanical failure of the container. Failures of packages containing plutonium oxide have occurred due to excessive gas generation. Oxide storage packages ruptured due to over-pressurization, resulting in contamination of the storage areas. Inspections of similar packages indicated pressurization from buildup of hydrogen and methane due to radiolytic and/or thermal degradation of the organic material. Four key aspects of safe storage standards were evaluated. The aspects are adequacy of the calcination process, resistance of the container to pressure, container sealing requirements, container resistance to radiation and corrosion.

Readiness Assessment Report: On July 29, 2003, a LANL Readiness Assessment (RA) Final Report was issued for the TA-55 Aqueous Recovery of Pu-238 Scrap process. The report documented observations based on procedures reviewed. A spill response repeated in NMT-9 work instructions states: "If a small spill (less than 250ml) occurs involving concentrated Pu-238 solutions, wipe up spill with cheesecloth." Specific warnings are included about use of cheesecloth in the HCP for the Aqueous Recovery of Pu-238 Scrap stating: "Spills involving high concentrations of Pu-238 may increase potential for fire with nitrated cheesecloth." The LANL RA Report further stated that: "This warning is correct but does not go far enough. The hazards of nitrated cellulose are well known and can be avoided. Experience has shown that cellulose rags, when exposed to nitric acid, form chemically unstable nitrated cellulose compounds that are unsafe for storage."

DOE Type A Accident Investigation: The DOE Type A Accident Investigation from March 16, 2000, *Plutonium-238 Multiple Intake Event,* Justifications of Need status was independently verified by the DOE Albuquerque Independent Safety Review Division at the request of LASO. Five actions had been determined to be incomplete and did not fulfill the commitments described within the Corrective Action Plan. Those five actions were reopened until commitments could be adequately addressed. The actions reopened were as follows. Conduct training to clarify work control at TA-55. Second, implement the room status logs. Third, write and implement an operator aid procedure. Fourth, develop an as-built implementation plan for TA-55 glovebox and auxiliary systems. Fifth, the Feedback and Improvement Board (F&IB) needs to review self-assessment data to determine the effectiveness of the On-the-Job, work management and training Laboratory Implementing Requirements (LIRs), and recommend remedial actions as necessary.

In summary, this Board did not find any evidence of communication between NMT-9 and the LANL managers of the DNFSB 94-1 and DNFSB 2000-1 implementation initiative. NMT-9 has stored a large number of packages in room 201B that were not included in the May 2003 LMSP PEP. The Board concluded that, based on the fact that packages in room 201B have been in storage for up to seven years and had no clear disposition path defined, they should be included in the LANL PEP. Furthermore, the Board concluded that, based on the discussion above regarding the LMSP PEP, there are other packaged materials at other locations at LANL of unknown status. The LMSP PEP implies that they are assumed to be safe until found to be otherwise, as opposed to assuming they are unsafe until found to be safe.

The Board reviewed management walkaround documentation of room 201 performed by NMT-9 since December 1996 to today. Seventeen management walkaround entries into room 201B were recorded since December 1996, and only one of these mentions an observation of the packages. There were no criteria for visual inspection of the packages during management walkarounds.

From interviews with the Board, it was evident that NMT-9 believed the LMSP PEP did not apply to program items on the floor. NMT-4, Nuclear Materials Management, and the LANL Material Recycle and Recovery Program Manager believed that the NMT-9 material stored in room 201B was not in the scope of the LMSP, and hence safe storage requirements and disposition of those packages was the responsibility of the Nuclear Energy (NE-50) program.

The Board did not find evidence that current NMT-9 procedures and work practices appropriately incorporated the recognized analyses described above. However, the Board did find evidence that operations in the Pu-239 areas had incorporated many of these same lessons learned in their activities. There was a lack of communication exchange between NMT organizations. The Board concluded that NMT-9 failed to implement lessons learned from previous events and to adequately institutionalize corrective actions.

The Board concluded that with respect to this accident, NMT management did not effectively communicate previously identified analyses and results of package failure modes and hazards analysis throughout the NMT organization. Safety analysis failed to adequately assess the hazard of a container failure with respect to Pu-238 operations, therefore accepting worker risk and worker uptake. The Board concluded that there is a lack of a systemic approach for trending, analyzing, formalizing, and disseminating lessons learned from the large number of documents related to the safe storage of packages in room 201B. The Board also concluded that LANL had not adequately addrssed weaknesses identified in the 2000 Type A Accident Investigation Report to date. Overall, the Board concluded that NMT's feedback and improvement program was not effective in identifying and correcting programmatic issues within the facility.

3.7.2 The NNSA/LASO Oversight Program

The Board reviewed the NNSA/LASO oversight program (including the current and the draft revision of standing instruction No.7) to define the programs, procedures, implementation, and the level of involvement by LASO to mitigate the known and documented problems previously identified. As part of the formal document review effort, the Board also interviewed several DOE personnel, including the TA-55 Facility Representatives (FR) and their respective managers.

The Board reviewed the FR assessment program that identifies assessments by functional areas and the quarterly reporting requirements used to identify and track any prior findings and or deficiencies. The Board determined that the overall LASO assessment program was deficient in identifying lessons learned from previous and similar incidents, and the Board identified that the current proposed "draft" revisions exclude those lessons learned as well. To further complicate the issue, the Board found that LASO possessed only limited ability to track their assessments or to trend or follow-up on their respective assessments due to the lack of a formal tracking system or database to support this expectation.

The Board could not find evidence that the DNSFB Recommendations 94-1 or 2000-1, or any similar recommendations, either internal or external, were included in the LASO assessment program. The Board also found program, line, and support responsibilities were not clearly defined and documented. These requirements or expectations between the program and field operations offices and the directives to implement such requirements down through organizational lines from the programs are informal.

LASO does not have a formal, stand-alone issues management tracking system. They use LANL's I-TRACK system to monitor issues and corrective action responses from similar events. The LASO oversight function includes the review of corrective actions from the DOE 2000 TA-55 Type A Accident Investigation. Additionally, an Albuquerque Operations Office Supplemental Directive on the tracking and closure of accident investigation corrective actions assigned the responsibility for verifying the completion of corrective actions to the Independent Safety Review Division. However, the roles and responsibilities for conducting these reviews has been complicated by the change in responsibilities due to the NNSA reorganization. (The Albuquerque Operations Office has been eliminated, and its functions, including those in the supplemental directive, are being reassigned to the site offices and the NNSA Service Center.) The review group that had been assigned the task of verifying completion has rejected a significant number of responses that did not provide a proper response or missed the intent by identifying an action related to unrelated materials (i.e., handling of Pu-239 vs. Pu-238).

The Board reviewed correspondence between LASO and LANL where numerous concerns and deficiencies had been presented to LANL management by LASO. LANL has committed to improve upon areas of concern, but has not yet identified specific actions to correct these issues. The Board reviewed the commitments made by LANL resulting from other recent events that demonstrated inefficiencies in the conduct of operations functional areas. LANL committed to encourage management to perform walkarounds of their respective areas, but the original commitment did not include the requirements, guidelines, criteria, and training for those managers. LASO did informally address this concern with LANL, however LANL had not responded to this issue at the time of this report. The Board reviewed a number of documented reports and letters that have addressed other significant and similar concerns to LANL, but where LANL had not provided a specific action plan to address the concerns, or had provided a commitment that was subsequently not implemented.

The Board concluded that LASO does not assess LANL's lessons learned program. The Board also concluded that LASO needs an issues management tracking system. Finally, the Board concluded that LANL is not adequately responsive to LASO, NNSA, and DOE concerns.

3.7.3 DOE/NNSA Headquarters' Oversight

NNSA NA-12, Assistant Deputy Administrator for Military Application and Stockpile Operations, approved the LANL Materials Stabilization Project, Project Execution Plan, on September 5, 2003. The objective of the LMSP is to stabilize and disposition the LANL inventory per DNFSB Recommendations 94-1 and 2000-1 and to ensure viable vault operations in support of the DOE national security mission. However, NA-12 believed that the LMSP PEP focused on the TA-55 vault and did not include or apply to Pu-238 operations. NA-12 considered Pu-238 operations to be an active program. In addition, NA-12 believed that the cradle-to-grave management of material/waste/residues as a result of NMT-9 operations was the responsibility of the program owner, the Office of Space and Defense Power Systems in the DOE Office of Nuclear Energy, Science, and Technology (NE-50). No formal memorandum of understanding exists between NNSA and NE-50 for the conduct of this program. Consequently, the LASO program office was not aware of program material accumulating in room 201B.

NE-50 has programmatic responsibilities for the Pu-238 operations conducted by NMT-9, however, they do not have responsibility for facility operations and facility safety at TA-55. Also, NE-50 does not have programmatic responsibility for the implementation of DNFSB Recommendations 94-1 and 2000-1. In addition, NE-50 was uncertain whether the cradle-to-grave management of material/waste/residues as a result of NMT-9 operations was their responsibility or that of the landlord, NA-12. The Board reviewed the Initial Fiscal Year (FY) 2003 NE-50 Program and Budget Guidance and the NMT-9 Cost Breakdown for FY03. As a result, the Board determined that NMT-9, NMT-4, Nuclear Materials Management, LANL, NNSA NA-12 and NE-50, and LASO did not appropriately manage the budget for Pu-238 operations.

The Board determined that weaknesses exist between execution of DOE/NNSA Headquarters' program responsibilities and execution of line responsibilities at the Site Office. At the most basic level, there was a failure to ensure that the full cradle-to-grave life cycle of the materials used in the Pu-238 operations was adequately funded, managed, and overseen. The Board concluded that NNSA/HQ line management oversight of LASO was not effective.

3.8 Implementation of Integrated Safety Management (ISM)

The UC/DOE Contract for management of the Los Alamos National Laboratory includes the requirement to have a documented safety management system. Since the late 1990s, LANL has devoted considerable effort to the implementation of ISM. Previous evaluations indicate LANL senior managers are knowledgeable about the ISM structure and have endorsed their commitment to working safely. However, the 2000 Type A Accident Investigation Board concluded that the events leading to the contamination of the workers in that accident demonstrated a lack of consistent application of the guiding principles and core functions of ISM, as they applied to the conduct of work in a potentially hazardous environment.

The Board for this Type B Accident Investigation reviewed the issues and concerns that have been identified in previous sections against the guiding principles of the core functions of ISM. Specific deficiencies are discussed below.

3.8.1 Roles and Responsibilities

Roles and responsibilities are assigned for all of the groups in NMT Division. The Board noted that several of the groups have involvement in this incident:

- The NMT-2, Actinide Process Chemistry Group, provides support of multiple stockpile stewardship activities including pit manufacturing, certification of MOX Fuels, and Vault Work off. The Project Manager for the 94-1 Implementation Plan resides in NMT-2.

- The NMT-4, Nuclear Materials Management Group, performs a variety of security and nuclear materials control and accountability services in support of the TA-55 operations. NMT-4 provides inventory planning and management, nondestructive assay (NDA) capability, interpreting and implementing nuclear material control and accountability regulations, nuclear material shipping and receiving services, and nuclear material storage.

- The FMU-7, TA-55 Facility Operations Group, manages the physical plant and facilities and provides technical and administrative support to ensure safe and continued facility operations; compliance with DOE Orders, state and local requirements; operations within the approved safety envelope; and provides a safe platform for program operations and research and development activities. FMU-7 has the requirements to schedule and maintain facility support activities including ventilation and other structural facility work.

- The NMT-9, Pu-238 Science and Engineering Group, supports the nuclear weapons program, national security and space missions through heat source development, component safety testing, heat source manufacture, and fuel recycling related to Pu-238. Room 201B is under the programmatic control of NMT-9.

- The NMT-16, Nuclear Materials Science Group, is charged with the characterization of new and aged pit construction materials and the development of technologies for advanced actinide materials characterization. NMT-16 scientists are familiar with the chemical and radiolytic processes of plutonium.

The Board found that there were multiple groups with knowledge and expertise in the storage of Pu-238 residues; however, the communications between these groups was ineffective. NMT-9 did not engage the expertise available in the other groups to assist in properly designing and implementing a process for the safe storage of Pu-238 residues in room 201B. The Board concluded that although LANL had established clear roles and responsibilities, NMT had not ensured that NMT-9 engaged those responsible personnel in support of the activities in room 201B.

3.8.2 Competence Commensurate with the Requirements of the Work

The Board did recognize that the RCTs and NMT employees were, in general, knowledgeable and competent. The Radiological Control Technicians performed the task of contamination screening on the workers and the Board Members proficiently during the re-entries. The NMT-9 employees provided excellent support to the Board during the investigation, surveying packages to identify and retrieve the suspect packages, opening the cans in gloveboxes, and providing technical support. However, as noted in other sections, the Board observed many occurrences of non-adherence to procedures, ad hoc operations without procedures, and a general complacency towards worker safety. Therefore, the Board concluded that while the workers demonstrated an adequate level of competence, NMT relied too heavily on this competence to compensate for an inadequate level of formality and rigor in the facility's operations.

3.8.3 Core Functions

The Board linked the conclusions of this investigation with the core functions of ISM:

Define the Work

- NMT failed to develop an effective hazard-control planning process to reduce the risks posed by the work to an acceptable level for the workers.

- NMT failed to identify the requirements to disconnect the storage cage seismic restraints as part of the tasks associated with conducting the inventories.

- LANL failed to identify the legacy issues associated with plutonium stored in slip-lid containers in room 201B.

Analyze the Hazards

- NMT failed to analyze the hazards and determine their likelihood and severity associated with the storage of Pu-238 residues in slip-lid containers in room 201B.

- NMT and HSR-1 failed to analyze the anticipated external dose for the workers conducting the inventory.
- LANL failed to identify the storage of plutonium in slip-lid containers in room 201B as a high consequence to the worker.

Develop and Implement Controls

- LANL failed to implement lessons learned regarding the preferred use of respirators in vaults when handling potentially damaged cans had been published.
- LANL failed to incorporate sufficient work controls for entering the high radiation area.
- LANL failed to implement adequate work controls to ensure that the storage cages in room 201B were meeting their intended functions.
- LANL failed to verify that the storage cage design was adequate.
- NMT failed to recognize that the seismic restraints were TSR level controls and establish requirements for ensuring they were promptly reinstalled if removed to conduct inventory activities.

Perform Work Safely

- E1 and E2 did not abide by the RWP requirements prescribing using 2-pairs of gloves, they did not sign in on the RWP within 30-days prior to entry, and they did not enter the room at the same time, possibly compromising the 2-person safety rule.
- RCT-1 did not abide by the RWP requirement of providing continuous coverage during movement of the shielding for the high radiation area in room 201B.
- RCT-1 did not conduct an adequate pre-job briefing prior to the entry into the high radiation area.
- E1 and E2 did not evacuate room 201B in accordance with the site training, which required evacuation to the corridor.
- The Operations Center staff did not accurately record the CAM alarms in rooms 201C and 204, they did not log in the CAM count data, and did not make notifications according to the requirements of the CAM Alarm Response procedure.

Feedback and Improvement

- The LANL 1994 Type C investigation and other discoveries of corroded packages in room 201B should have raised the awareness level of the hazards of storage of plutonium in slip-lid containers. Among other things, the 1994 Type C Board recommended: (1) formal daily checks should be established to visually check all cans containing rags originating from the Pu-238 operations, including the cans stored in room 201B, room 204, and in any other room at TA-55; (2) NMT-9 should implement immediately a procedure to document the source of all the cheesecloth rags placed in each can. There was evidence that where actions had been taken, they were not effective or complete.
- The 1994 *Plutonium Working Group Report on the Vulnerabilities of Plutonium Storage* specifically identified the LANL vulnerability of handling degraded packages containing plutonium oxide from metal oxidation as an event likely to occur within 2-5 years with a high consequence to the worker.
- The 1998 DOE Standard *Guide for Good Practices for Occupational Radiological Protection in Plutonium Facilities* recommended that organics (plastics) must be excluded from the primary container for plutonium oxide. Plutonium oxides are best stored in containers fitted with a rupture disk in series with a vented stainless-steel frit container, and surveillance of the stored materials is required.

- The 1999 LANL *Summary of Plutonium Oxide and Metal Storage Package Failures* identified two primary failure modes of plutonium containers: a) metal oxidation due to non-airtight packages, and b) gas pressurization from radiolytic and thermal degradation of inadequately stabilized material.

- The 1999 LANL report cited numerous technical reports and publications describing failure of packages containing plutonium oxide. The LANL report concluded that the majority of failures occurred in the oxide storage packages due to over-pressurization. Inspections of similar packages indicated pressurization from buildup of hydrogen and methane due to radiolytic and thermal degradation of the organic material.

- The 2000 DOE Standard *Stabilization, Packaging, and Storage of Plutonium-Bearing Materials* explains that the presence of low levels of chloride can catalyze cracking in stainless steel. The available moisture, rather than the available chloride limits the extent of the corrosion.

The Board concluded that the implementation of ISM within NMT is ineffective and inadequate for the level of hazard present in the workplace.

3.9 Management Systems

The Board noted that numerous factors contributed to the long-term storage of unstabilized Pu-238 bearing materials in room 201B and the eventual degradation and failure of the packages.

These factors included (1) the shutdown of large scale treatment of Pu-238 residues via the LANL incinerator in 1989; (2) changing mission and program requirements in the mid 1990s resulted in the generation of significant amounts of Pu-238 contaminated material; (3) lack of immediate storage space in the vault contributed to storing material in room 201B; (4) continued use of cellulose rags in Pu-238 lines coupled with restrictive disposal requirements necessitated the need to establish appropriately sized treatment capabilities to dispose of increasing volumes of Pu-238 residue; and (5) lack of clear roles and responsibilities within DOE and LANL for the establishment and ongoing funding for the stabilization, packaging and disposal of Pu-238 generated materials allowed long-term storage with no action to continue. Each of these factors is described below:

<u>Shutdown of Incinerator Operations</u>

Prior to January 15, 1989, materials with Pu-238 residues were incinerated at LANL. At that time the State of New Mexico issued a one-year moratorium on incineration of mixed waste. The moratorium was later made permanent, and LANL did not restart incinerator operations. As a result, the packages containing Pu-238 residues and organics accumulated in room 201B until they could be treated and disposed.

<u>Increased Production of Pu-238 Contaminated Material</u>

Increased programmatic requirements for Pu-238 production coupled with decreasing domestic sources of Pu-238 resulted in the generation and retention of more residues. This occurred primarily with the Cassini Mission from 1995-1997 and continued to increase in the late 1990s with additional NASA and DOD mission requirements. As the availability of Pu-238 diminished, it became economically feasible to process the residue and recover the Pu-238. As a result, the packages remained in room 201B for future processing to recover the residue.

<u>Limited Storage Space</u>

Due to a lack of available space in the vault, process materials containing Pu-238 residues were stored in room 201B. The packages accumulated in room 201B without the additional controls that would have been applied had they been stored in the vault.

<u>Disposal and Treatment Options</u>

The management/treatment of waste for PF-4 operations are driven by the disposal method available for the material. WIPP is the primary path for disposal of transuranic waste. Therefore the waste acceptance criteria (WAC) and shipping requirements imposed by

WIPP are important and may be restrictive. In addition, the WIPP Land Withdrawal Act limited WIPP to "Defense" waste. This has caused some question as to the legality of the wastes from Pu-238 committed to NASA missions being disposed at WIPP. Defense and non-defense Pu-238 has historically come from the same source, been commingled in the same processing lines, and generally not segregated. A decision was made to allow Pu-238 waste created prior to 1998 to be disposed of at WIPP. Furthermore, DOE's General Counsel (GC) had made a legal basis determining that segregation of Pu-238 between defense and non-defense use was not required. This analysis was performed for initial WIPP shipments, however the GC's rationale was not widely disseminated. Consequently, waste management officials at DOE decided that the waste should be segregated. Therefore all waste created from 1998 to today has been segregated using a variety of methods that assured a proportional amount of waste was designated as "Non Defense." Currently, LANL and LASO are working to apply the GC's rationale to allow all Pu-238 wastes to be eligible for WIPP disposal.

WIPP limitations on Pu-238 wastes are generally driven by shipment considerations due to gas build-up caused by radiolytic effects. Some attempts have been made to allow higher levels of Pu-238 with special shipment handling procedures to be used. The disposal of unstabilized cheesecloth at WIPP is highly limited by the allowable gram content (less than 0.2 grams of Pu-238 per drum). As a result, it becomes necessary to pyrolize these waste streams in to order to stabilize the material, which would allow increased disposal limits and reduced disposal costs for Pu-238 contaminated waste. Also, for residues that have a mass of Pu-238 worth recovering, pyrolysis is the first step in the scrap recovery process. Therefore, an adequate pyrolysis capacity to treat cheesecloth is necessary, regardless of whether the material will be shipped to WIPP or used as feed material for the aqueous scrap recovery process. The reduction of organics in the shipment (i.e., bagless containers) would also allow for higher drum content limits.

Cheesecloth is a preferred cleaning agent for glovebox cleaning and was used widely in TA-55 during the 1980's. However, cheesecloth has properties that make it undesirable for storage in this form. Potential reaction products with nitric acid and its decomposition/gas generation processes are problematic for long-term storage (see section 3.3). These undesirable effects were mitigated in the 1980's by the use of combustion (incineration) to treat these waste streams relatively soon after generation. This treatment is also required if the material is expected to be processed by aqueous scrap recovery or is preferable to meet the WIPP WAC. The banning of incineration due to changing environmental requirements occurred in 1989. Replacements to the cheesecloth were identified although they were less effective. In TA-55, the use of cheesecloth in the Pu-239 operations that use nitric acid was eliminated; however, Pu-238 operations continue to use cheesecloth with nitric acid.

Pyrolysis was identified as a replacement to combustion, however, due to facility concerns, NMT-9 was restricted from using the Pu-239 pyrolysis unit to process Pu-238 residues. A separate system was established for Pu-238 to prevent mixing the waste streams. The Pu-238 pyrolysis unit was apparently unable to treat the amount of combustible (including cheesecloth) waste being produced in a timely manner, although the Pu-239 operations apparently have been able to pyrolize cheesecloth relatively soon after generation, leaving no cellulose packages currently in the vault. The Pu-238 combustible residues therefore began to accumulate in room 201B awaiting pyrolysis.

Material that was pyrolized would also be stored in room 201B awaiting scrap recovery. NMT-9 has a bench scale scrap recovery operation with limited capacity. A full-scale scrap recovery line is in the readiness process, which will provide greater capacity. However, material initially slated for this process is higher content scrap, and therefore this effort will not immediately alleviate the storage problems in room 201B. In addition, the packages used in room 201B were not functionally designed (see Section 3.4) to handle these unstable residue forms for any length of time. The Pu-238 operations initiated the development of a molten salt oxidation (MSO) process to upgrade their combustible treatment capability. To date the MSO process, due to technical difficulties, has not reached an operational throughput to be a factor in reducing treatment of combustible residue. This has added to the accumulation of material awaiting pyrolysis in room 201B. Currently, Pu-238 operations continue to use their pyrolysis and MSO units to treat limited quantities of materials. Material and packages sent to pyrolysis tend to be those of highest external radiation levels — not necessarily the oldest. Due to this decision, many packages have been stored in 201B for over seven years.

The Board concluded that NMT-9 has an inadequate residue processing capability, which has resulted in Pu-238 residue being left in unknown and unsafe conditions for an inappropriate length of time.

Program Funding

In October of 1998, NMT-9 sent a memo to DOE/NE requesting approval for generating waste with no available disposal path. Furthermore, the memo stated that NMT-9 would need to develop a corrective action plan for the disposal of newly generated Pu-238 waste. The memo further states that the "development of a conceptual design for feed pretreatment (i.e., size reduction) and MSO processing will serve as a corrective action plan for disposal of Pu-238 contaminated waste at LANL." NMT-9 sent a final memo to DOE/NE in November of 1998 that NE has not acted on.

In January 1999, NMT-9 sent another waste generation approval request package to DOE/NE for approval. This package described two processes, (1) heat source fabrication, and (2) aqueous recovery operations, that will generate waste. This package resulted in an approved Environmental Impact Statement (EIS) that stated that TRU waste will be treated and stored onsite pending disposal. The EIS stated that there was currently no disposal treatment path for this waste. However, applicable treatment technologies have been reviewed and several viable technologies are currently being evaluated such as MSO, mediated electrochemical oxidation (MEO), hydrothermal oxidation, and pyrolysis.

An accelerated site technology deployment proposal, "Advanced Technologies for Stabilization of Pu-238 Contaminated Combustible Waste" was submitted to DOE/EM. Additional funding was also requested from DOE/NE for FY99 to develop a conceptual design for processing TRU combustible waste.

NMT-9 continued to submit packages to DOE for approval until they were finally approved by DOE/AL in August of 2000. In the response, the DOE/AL Manager authorized the continued generation of waste with no disposal path.

NMT-9 baselined the funding requirements in their submittals, which included $10M total cost to store the Pu-238 waste at TA-54 ($10M over 10 years plus treatment and disposal cost) and $54M for WIPP disposal. In 1999, NE-50 committed to provide $29,000 in treatment costs in FY98, $38,000 in FY99, and $117,000 in FY00 to make modifications to segregate non-DP waste from DP waste. In 1999 NE also committed $2.1M in FY99 and FY00 to implement and deploy MSO.

In February 2001 and July 2002, NMT-9 submitted packages again requesting approval to generate waste with no disposal path, and these still have not been approved by NNSA. As a result, by default NNSA has accepted and approved the No Action, No Treatment, and Indefinite Storage option of $62,000 per year vice the WIPP disposal option of $1.2M.

The Board concluded that DOE and NNSA did not establish and implement clear roles and responsibilities for establishing and providing funding for ultimate disposal of Pu-238 waste generated during NMT-9 operations.

3.10 Barrier Analysis

Barrier analysis is based on the premise that hazards are associated with all tasks. A barrier is any management or physical means used to control, prevent, or impede the hazard from reaching the target (i.e., persons or objects that a hazard may damage, injure, or harm). The results of the barrier analysis are integrated into the events and causal factors chart to support the development of causal factors. Table 3-1 contains the Board's summary of physical and management barriers that failed to perform as intended, thereby contributing to the accident. Appendix B contains the complete barrier analysis.

Table 3-1 Summary of Failed Physical and Management Barriers.

Hazard	Airborne Contamination
Management System Barrier	Disposition path for Pu-238 Technical Basis Documents Hazards Analysis Communication of worker safety issues Radiological Work Permit Implementation Plan in response to DNFSB 94-1 and 2000-1 Surveillance Program Lessons Learned Administrative Controls
Physical System Barrier	Packaging Configuration Stabilization of Material Vault Storage
Target	**Worker**

3.11 Change Analysis

Change Analysis examines planned or unplanned changes that caused undesirable results related to the accident. This process analyzes the difference between what is normal, or expected, and what actually occurred prior to the accident. The results of the change analysis are integrated into the events and causal factors chart to support the development of causal factors. The Change Analysis is presented in Table 3-2.

3.12 Causal Factors Analysis

A causal factors analysis was performed in accordance with the DOE Workbook *Conducting Accident Investigations*. Causal factors are the events or conditions that produced or contributed to the occurrence of the accident and consist of the direct, contributing, and root causes.

The **direct cause** is the immediate event or condition that caused the accident. The Board concluded that the direct cause of the accident was the release of airborne contamination from a degraded package that contained cellulose material and Pu-238 residues.

Contributing causes are events or conditions that collectively with other causes increase the likelihood of the accident but that individually did not cause the a accident. A summary of the Board's causal factors analysis is presented in Table 3-3.

Root causes are the events or conditions that, if corrected, would prevent recurrence of this and similar accidents. The root causes are derived from the contributing causes. The Board concluded that there were three root causes for this event:

RC1 The Nuclear Materials Technology Division failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers handling Pu-238. (CC1, CC2, CC3, CC4, CC5, CC6, CC7)

RC2 The Department of Energy, the National Nuclear Security Administration, and Los Alamos National Laboratory failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (CC1, CC3, CC4, CC6, CC7, CC8, CC10, CC11, CC12, CC13)

RC3 The Department of Energy, the National Nuclear Security Administration, and Los Alamos National Laboratory managed the Defense Nuclear Facility Safety Board's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (CC1, CC5, CC6, CC8, CC9, CC10, CC11, CC12, CC13)

Table 3-2 Change Analysis.

Prior to Accident	Normal	Change	Effect
Mission requirements for Pu-238 increased (e.g., NASA) and domestic sources ceased production.	Pu-238 is available for processing from domestic sources.	As the availability of Pu-238 diminished, it became economically feasible to process the residue.	The packages remained in room 201B for future processing to recover the residue.
Residues were stored in room 201B were awaiting pyrolization and molten salt processing.	Prior to January 15, 1989, materials with Pu-238 residues were incinerated at LANL.	The State of New Mexico issued a moratorium on the incineration of mixed waste.	The packages containing Pu-238 residues and organics accumulated in room 201B.
Due to a lack of available space in the vault, process materials containing Pu-238 residues are stored outside of the vault in room 201B.	Packages containing Pu-238 residues are stored in the vault.	Process residues are stored in room 201B.	The packages accumulated in room 201B without the additional controls that would have been applied had they been stored in the vault.
The inner can, plastic bag and outer can all failed.	Inner cans, plastic bags, and outer cans are known to fail, but evidence of all three failing on a single package had yet to be observed at LANL.	The risk of the failure of all layers of packaging is accepted.	Airborne release of Pu-238.

Table 3-3 Causal Factors Analysis Summary.

No.	Contributing Cause	Discussion
CC1	NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations.	❑ Sufficient information was available to demonstrate that the failure mechanisms observed were previously recognized and known to NMT. ❑ The Board identified several concerns with the adequacy of the facility's authorization basis in addressing the activities conducted in room 201B. ❑ There was no HCP for room 201B, as contrasted with the HCP for the PF-4 Vault. ❑ Controls for worker safety issues identified in the SAR were not developed or flowed down into implementing procesures. ❑ NMT did not take action based on previous experiences with failed packages within the facility. ❑ Packaging materials and practices were not in compliance with facility procedures.

No.	Contributing Cause	Discussion
		❑ LANL's safety culture allowed complacency, failure to respect hazards, and acceptance of risk without understanding consequences. ❑ The residue processing capabilities are not sized appropriately to maintain an adequate throughput to minimize the accumulation of packages in room 201B.
CC2	NMT failed to establish and implement controls for storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures.	❑ Sufficient information was available to demonstrate that the failure mechanisms observed were previously recognized and known to NMT. ❑ Failure mechanisms could attack all barriers simultaneously. ❑ There were no performance requirements for packaging configurations, routine surveillances, storage configurations, or handling procedures. ❑ Routine handling of the package was sufficient to dislodge internal rust deposits in seams, allowing venting of pressure. ❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ There was no HCP for activities in room 201B.
CC3	NMT failed to adequately establish and implement worker level controls for activities in room 201B.	❑ There was no HCP for activities in room 201B. ❑ Worker hazards associated with the handling of packages were not analyzed, and no controls were implemented. ❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ There was a significant reliance on worker knowledge and experience. ❑ Procedural non-compliances were observed in a wide range of worker activities. ❑ RWPs were used as work control documents beyond the scope of LANL's requirements. ❑ LANL's safety culture allowed complacency, failure to respect hazards, and acceptance of risk without understanding consequences. ❑ NMT's feedback and improvement program was ineffective in responding to lessons learned from previous experiences at both the facility and other facilities in the DOE complex. ❑ The LANL ISM requirements at the work activity level are not adequately implemented by NMT. ❑ There was no formal ALARA review of the high radiation area within room 201B.

No.	Contributing Cause	Discussion
CC4	NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected.	❑ LANL's safety culture allowed complacency, failure to respect hazards, and acceptance of risk without understanding consequences. ❑ NMT's feedback and improvement program was ineffective in responding to lessons learned from previous experiences at both the facility and other facilities in the DOE complex. ❑ Multiple operations were observed that were inconsistent with procedures and site training. ❑ Weaknesses identified in the 2000 Type A accident investigation of the same operation have not been adequately addressed to date by LANL. ❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ There was a significant reliance on worker knowledge and experience. ❑ The LANL ISM requirements at the work activity level are not adequately implemented by NMT. ❑ There was no specific criteria established for NMT management walkarounds of the facility.
CC5	NMT-9 failed to promptly stabalize materials of known incompatibilities or instabilities.	❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ The residue processing capabilities are not sized appropriately to maintain an adequate throughput to minimize the accumulation of packages in room 201B. ❑ Problems with storage of plutonium-bearing materials, and the need for prompt stabilization and proper packaging, was known prior to the onset of this activity in 1996. ❑ There is visible evidence of multiple failure mechanisms currently in progress within packages stored in room 201B.
CC6	NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B.	❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ NMT's feedback and improvement program was ineffective in responding to lessons learned from previous experiences at both the facility and other facilities in the DOE complex. ❑ The LANL ISM requirements at the work activity level are not adequately implemented by NMT. ❑ There is visible evidence of multiple failure mechanisms currently in progress within packages stored in room 201B.

No.	Contributing Cause	Discussion
		❑ Sufficient information was available to demonstrate that the failure mechanisms observed were previously recognized and known to NMT. ❑ Packaging materials and practices were not in compliance with facility procedures.
CC7	NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B.	❑ The Board identified several concerns with the adequacy of the facility's authorization basis in addressing the activities conducted in room 201B. ❑ Some of the seismic restraints of the cages, a TSR level control, were found to be either broken or not properly attached. ❑ Packaging materials and practices were not in compliance with facility procedures. ❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ Multiple operations were observed that were inconsistent with procedures and site training. ❑ There was a significant reliance on worker knowledge and experience. ❑ Controls for worker safety issues identified in the SAR were not developed or flowed down into implementing procedures. ❑ Packages were found to be stored on the floor and in other locations outside of the cages, but they were not included in the SAR analysis.
CC8	LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements.	❑ Multiple operations were observed that were inconsistent with procedures and site training. ❑ Controls for worker safety issues identified in the SAR were not developed or flowed down into implementing procedures. ❑ Packages were found to be stored on the floor and in other locations outside of the cages, but they were not included in the SAR analysis. ❑ The Board identified several concerns with the adequacy of the facility's authorization basis in addressing the activities conducted in room 201B. ❑ Packaging materials and practices were not in compliance with facility procedures. ❑ NMT-9 had observed other packages with significant degradation, but did not change practices or procedures. ❑ There were no performance requirements for packaging configurations, routine surveillances, storage configurations, or handling procedures.

No.	Contributing Cause	Discussion
		❑ Although the storage cages were listed as Design Features, there were no Functional Requirements for them. ❑ There was no HCP for activities in room 201B.
CC9	LANL failed to identify all packages that should have been included in the program execution plan for DNFSB Recommendation 2000-1.	❑ Based on the fact that packages in room 201B have been in storage for up to seven years and had no clear disposition path defined, they should be included in the LANL PEP. ❑ According to the LMSP PEP, there are other packaged materials at other locations at LANL of unknown status. The report implies that they are assumed to be safe until found to be otherwise, as opposed to assuming they are unsafe until found to be safe.
CC10	DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations.	❑ LASO did not verify that the design and implementation of the seismic restraints for the cages were adequate. ❑ Multiple operations were observed that were inconsistent with procedures and site training. ❑ Controls for worker safety issues identified in the SAR were not developed or flowed down into implementing procedures. ❑ Packages were found to be stored on the floor and in other locations outside of the cages, but they were not included in the SAR analysis. ❑ The Board identified several concerns with the adequacy of the facility's authorization basis in addressing the activities conducted in room 201B. ❑ The residue processing capabilities are not sized appropriately to maintain an adequate throughput to minimize the accumulation of packages in room 201B. ❑ LANL's safety culture allowed complacency, failure to respect hazards, and acceptance of risk without understanding consequences. ❑ NMT's feedback and improvement program was ineffective in responding to lessons learned from previous experiences at both the facility and other facilities in the DOE complex. ❑ The LANL ISM requirements at the work activity level are not adequately implemented by NMT. ❑ Weaknesses identified in the 2000 Type A accident investigation of the same operation have not been adequately addressed to date by LANL.

No.	Contributing Cause	Discussion
CC11	DOE/NE and NNSA failed to establish clear funding and oversight responsibilities between DOE program elements for the NMT-9 work conducted by NNSA but funded by NE.	❑ There was confusion within NE and NNSA over the oversight responsibilities for the NMT-9 operations funded by NE. ❑ There is no formal agreement in place between NE and NNSA regarding these activities. ❑ There was no defined disposition path for the materials in storage in room 201B. ❑ The residue processing capabilities are not sized appropriately to maintain an adequate throughput to minimize the accumulation of packages in room 201B.
CC12	DOE and NNSA failed to provide comprehensive and adequate requirements and guidance for the packaging and storage of Pu-238 bearing materials.	❑ There are no DOE requirements or guidance applicable to the in-process storage of plutonium-bearing materials. ❑ The interim and long-term storage requirements for plutonium either exclude or do not provide adequate consideration for Pu-238 bearing materials. ❑ Programs established to address Pu-238 materials have been re-scoped to exclude the LANL Pu-238 operations.
CC13	DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations.	❑ Based on the fact that packages in room 201B have been in storage for up to seven years and had no clear disposition path defined, they should be included in the LMSP PEP. ❑ According to the LMSP PEP, there are other packaged materials at other locations at LANL of unknown status. The report implies that they are assumed to be safe until found to be otherwise, as opposed to assuming they are unsafe until found to be safe. ❑ There are no DOE requirements or guidance applicable to the in-process storage of plutonium-bearing materials. ❑ The interim and long-term sotrage requirements for plutonium either exclude or do not provide adequate consideration for Pu-238 bearing materials. ❑ Programs established to address Pu-238 materials have been re-scoped to exclude the LANL Pu-238 operations. ❑ The oversight plan for LASO does not include a review of LANL's implementation of the DNFSB 94-1 and 2000-1 recommendations.

4.0 Judgments of Need

Judgments of Need (JON) identify the managerial controls and safety measures that the Board concluded are necessary to prevent or minimize the probability of recurrence of this accident. They are derived from the Causal Factors and are directed at guiding managers in the development of corrective actions. The Causal Factors are identified in Section 3.12.

No.	Judgment of Need	Related Causal Factors
JON 1	NMT needs to evaluate the Pu-238 operations and ensure that the residues and wastes are minimized, those generated are packaged with properly designed packages in accordance with DOE approved criteria, and a final deposition plan is developed and approved by LASO.	❑ The Nuclear Materials Technology Division (NMT) failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ DOE and NNSA failed to provide comprehensive and adequate requirements and guidance for the packaging and storage of Pu-238 bearing materials. (CC12)
JON 2	NMT needs to conduct a comprehensive hazard analysis for the packaging, handling, and storage of all Pu-238 bearing materials within TA-55, including that in-process and interim storage. The lessons learned from other plutonium packaging experiences in DOE need to be included in this hazard analysis.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1)

No.	Judgment of Need	Related Causal Factors
		❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)
JON 3	NMT needs to develop and implement controls to protect the workers and, if necessary, the public and the environment, from the hazards identified as a result of the analysis conducted for JON 2.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)

No.	Judgment of Need	Related Causal Factors
JON 4	NMT needs to verify that all hazard controls, including those from JON 3, are formally incorporated into specific implementing work control documents.	❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 5	NMT needs to evaluate the differences between the analysis in the current authorization basis and the as-found conditions in room 201B via the USQ process. This evaluation should include, as a minimum: ❑ Release of Pu-238 during handling, assuming failure of all packaging boundaries; ❑ Storage of Pu-238 packages outside of cages; ❑ Adequacy of the seismic restraints; ❑ Reconsideration of the absence of load limits for Pu-238 in room 201B.	❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7)

No.	Judgment of Need	Related Causal Factors
JON 6	NMT needs to establish and implement a periodic, formal self-assessment program with performance-based criteria that will ensure work is performed safely.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 7	NMT needs to establish and implement a process to ensure that the flow down and effectiveness of worker hazard controls derived from and documented in the safety envelope (e.g., SAR, TSR, SER, HCP, SOP, etc.) have been verified prior to authorizing individual nuclear facility activities.	❑ NMT failed to conduct an adequate and comprehensive hazard analysis of the packaging, storage, and inventory of residues generated in the Pu-238 operations. (CC1) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4)

No.	Judgment of Need	Related Causal Factors
		❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8)
JON 8	LANL needs to conduct a site-wide evaluation to identify all packages containing fissile materials and other radioactive substances, and ensure these materials are provided with the same degree of management attention as those currently identified in the DNFSB 2000-1 PEP, regardless of location or current use designation. The safety of the packages identified needs to be determined by comparison against established criteria, and prompt compensatory action needs to be taken for those found to be of question or concern. All containers identified in this evaluation need to added to the LANL Integrated Surveillance Program.	❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to incorporate lessons learned from previous TA-55 events, technical evaluations from Pu-239 operations, and ongoing R&D into packaging requirements for Pu-238 stored in room 201B. (CC6) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ LANL failed to identify all packages that should have been included in the program execution plan for DNFSB Recommendation 2000-1. (CC9) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)

No.	Judgment of Need	Related Causal Factors
JON 9	LASO needs to establish and implement a criteria-based process to periodically evaluate the flow down and effectiveness of worker hazard controls derived from and documented in the safety envelope (e.g., SAR, TSR, SER, HCP, SOP, etc.) for LANL nuclear facility activities.	❑ The DOE, the NNSA, and LANL failed to adequately evaluate and understand the magnitude of the worker safety risks that they have accepted for the activities conducted by the Pu-238 Science and Engineering Group. (RC2) ❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT failed to adequately establish and implement worker level controls for activities in room 201B. (CC3) ❑ NMT failed to ensure that worker safety issues were being proactively identified, evaluated, and corrected. (CC4) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ NMT failed to identify and evaluate the differences between the SAR assumptions and the applicable procedures, practices, and as-found conditions in room 201B. (CC7) ❑ LANL failed to ensure that NMT operations were in compliance with LANL institutional requirements. (CC8) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)
JON 10	LASO needs to evaluate NMT-9 program activities for consistency to authorized budgets and DOE's life cycle (cradle-to-grave) management expectations.	❑ NMT failed to balance management attention and resources between accomplishing the programmatic mission and providing an appropriate level of protection for the workers. (RC1) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10)

No.	Judgment of Need	Related Causal Factors
		❑ DOE/NE and NNSA failed to establish clear funding and oversight responsibilities between DOE program elements for the NMT-9 work conducted by NNSA but funded by NE. (CC11)
JON 11	NNSA needs to validate the accuracy and completeness of LANL's revised 2000-1 PEP (after completion of JON 8) and ensure that compensatory measures are promptly instituted to mitigate the level of risk until all PEP activities are completed.	❑ LANL failed to identify all packages that should have been included in the program execution plan for DNFSB Recommendation 2000-1. (CC9) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)
JON 12	NNSA and DOE/NE need to develop a formal agreement defining the roles and responsibilities for the funding and oversight of safety-related activities associated with the NMT-9 work performed for NE missions.	❑ DOE, NNSA, and LANL failed to adequately oversee the cradle-to-grave management of the NMT-9 operations. (CC10) ❑ DOE/NE and NNSA failed to establish clear funding and oversight responsibilities between DOE program elements for the NMT-9 work conducted by NNSA but funded by NE. (CC11)
JON 13	NNSA needs to develop a comprehensive set of requirements for the safe stabilization, storage, and disposal of Pu-238 bearing materials, to cover the full life cycle of this material.	❑ The DOE, the NNSA, and LANL managed the DNFSB's Recommendations 1994-1 and 2000-1 as projects for addressing legacy materials storage rather than as an effort to mitigate potential hazards to workers. (RC3) ❑ NMT failed to establish and implement controls for the storage of Pu-238 residues, such as analysis and design of the packaging, controls on contents of packages, performance criteria, inspection and surveillance criteria, load limits on room 201B, controls on time-in-storage, and packaging procedures. (CC2) ❑ NMT-9 failed to promptly stabilize materials of known incompatibilities or instabilities. (CC5) ❑ DOE and NNSA failed to provide comprehensive and adequate requirements and guidance for the packaging and storage of Pu-238 bearing materials. (CC12) ❑ DOE failed to ensure that commitments established in response to implementation plans for DNFSB Recommendation 2000-1 were adequately implemented for both legacy materials and ongoing operations. (CC13)

5.0 Board Signatures

Date Oct. 2, 2003

Douglas M. Minnema, Ph.D., CHP, Chairperson
DOE Accident Investigation Board
National Nuclear Security Administration
NNSA Service Center

Date 10/2/2003

Donald Brady, CHP, Member
DOE Accident Investigation Board
National Nuclear Security Administration
NNSA Sercice Center

Date 10/2/2003

Dr. Scott DeClue, Ph.D., PE, Member
DOE Accident Investigation Board
U.S. Department of Energy
Savannah River Operations Office

Date 10/2/03

Charles Hughey, Member
DOE Accident Investigation Board
Narional Nuclear Security Administration
Y-12 Site Office

Date 10/02/2003

Joanne D. Lorence, Member
DOE Accident Investigation Board
National Nuclear Security Administration
Los Alamos Site Office

Date 10/2/03

Lynn Maestas, Member
DOE Accident Investigation Board
National Nuclear Security Administration
NNSA Service Center

Date 10/2/03

Al MacDougall, Member
DOE Accident Investigation Board
National Nuclear Security Administration
NNSA Service Center

Date 10/2/03

Martin Salazar, Member
DOE Accident Investigation Board
U.S. Department of Energy
Savannah River Operations Office

6.0 Board Members, Advisors, and Staff

Chairperson:	Douglas M. Minnema, Ph.D., CHP	NNSA Service Center
Members:	Donald Brady, CHP	NNSA Service Center
	Dr. Scott DeClue, PE	DOE Savannah River Operations Office
	Charles Hughey	NNSA Y-12 Site Office
	Joanne D. Lorence	NNSA Los Alamos Site Office
	Lynn Maestas	NNSA Service Center
	Al MacDougall	NNSA Service Center
	Martin Salazar	DOE Savannah River Operations Office
Laboratory Observer:	Stephen Costigan	Los Alamos National Laboratory
Administrative Support:	Sandra Robinson	SAIC
Technical Editor:	Robin Phillips	SAIC
Production Support:	Daniel Gagne	SAIC
Legal Review:	Henry Garson, Esq.	NNSA General Council

Appendix A: Board Letter of Appointment

United States Government

Department of Energy

memorandum

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

DATE: AUG 1 1 2003

REPLY TO ATTN OF: OFO:1DS-009

SUBJECT: Type B Investigation – Airborne Release at TA-55, PF-4

TO: Those on the Attached List

I hereby establish a Type B Accident Investigation Board to investigate the incident that occurred at the Los Alamos National Laboratory's TA-55, PF-4 facility on August 5, 2003. I have determined that it meets the requirements established in DOE Order 225.1A, "Accident Investigations" dated November 26, 1997, for a Type B Accident Investigation Board. If, during this investigation, any individual is confirmed to have a central tendency internal exposure of equal to or greater than 25-rem committed effective dose equivalent (CEDE), the investigation will be upgraded to a Type A Accident Investigation Board.

I appoint Douglas Minnema, National Nuclear Security Administration (NNSA) Service Center, as the Board Chairperson. The team will consist of:

Board Members:
Donald Brady, NNSA Service Center
Scott DeClue, Savannah River Operations Office
Charles Hugey, NNSA, Y-12 Site Office
Joanne Lorrence, NNSA, Los Alamos Site Office
Lynn Maestes, NNSA Service Center

Trained Investigator:
Lynn Maestes, NNSA Service Center

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

The Board will be chartered for a time-period of August 13, 2003, to October 3, 2003. In the event that the Board cannot conclude its investigation by October 3, 2003, the investigation will be extended until the Board's investigation is complete.

The scope of the Board's investigation will include, but is not limited to, identifying all relevant facts; analyzing the facts to determine the direct, contributing, and root causes of the accident; developing conclusions; and determining the judgments of need that, when implemented, should prevent the recurrence of the accident. The investigation will be conducted in accordance with DOE Order 225.1A and will specifically address the role of DOE, contractor organizations, and management

Addressee 2 AUG 1 1 2003

systems as they may have contributed to the accident. The scope will also include any deficiencies related to Integrated Safety Management System implementation and the application of lessons learned from similar accidents within DOE.

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

This report should be provided to me for acceptance by October 3, 2003. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

E. Dennis Martinez for:
Ralph E. Erickson
Manager

Distribution:
James Mangeno, NA-1, HQ/FORS
Richard Stark, EH-53, HQ/GTN
Dale Dunsworth, NA-124, HQ/GTN
Richard Crowe, NZ, HQ/GTN
Dennis Martinez, OOM, LASO
Gerald Schlapper, SSA, LASO
Joe Vozella, OFO, LASO
David Styers, OFO, LASO
Steve Yarbro, NMT, LANL, MS-E500

After the initial chartering of the Type B investigation, Al MacDougall, NNSA Service Center, and Martin Salazar, Savannah River Operations Office, were added to the investigation Board.

Appendix B: Barrier Analysis

Hazard: Airborne Contamination		Target: Worker	
What were the barriers?	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect accident?**
Approved disposition path for the Pu-238 residue	Failed	Material was generated and stored without a disposition path.	The material in room 201B accumulated beyond the NMT-9 ability to process in an expeditious manner.
Technical Basis Documents	Failed	The technical basis for the storage of residues was not adequately documented nor understood.	Inadequate stabilization and packaging of the Pu-238 residues led to an airborne release of radioactivity.
Hazard Analysis	Failed	The worker safety hazards associated with the storage configuration were not adequately analyzed.	Inadequate PPE and inadequate stabilization and packaging of the Pu-238 residues led to an airborne release of radioactivity.
Communication of worker safety issues from 1996 and 2002 Safety Analysis Reports	Failed	Even though the release of radioactive material from the containers in room 201B had been postulated in both the 1996 and 2002 SAR, the hazard had not been institutionalized into their worker safety program.	Controls were not put into place to protect the workers.
Packaging Configuration	Failed	Selection of improper materials for packaging of Pu-238 residues that have not undergone stabilization.	The contents of package reacted with each of the three layers of packaging and led to the release of the radioactive material.
Stabilization of Material	Not used	The material in the packages in room 201B was not stabilized prior to packaging.	If the material had been stabilized prior to packaging, the package would not have failed in the same manner.
Vault Storage	Not used	The material in room 201B was not stored in the vault.	Had the material in room 201B been stored in the vault, there would have been increased emphasis on stabilization and proper packaging of the material.
Radiological Work Permit	Not adequately developed or utilized	a) The RWP did not fully capture the inhalation hazard documented in the SAR. b) E2 never signed the current RWP and E1 had signed it 7 months preceding the event.	a) Respiratory protection was not used. b) The workers did not adhere to all of the requirements of the RWP.

Hazard: Airborne Contamination		Target: Worker	
What were the barriers?	**How did each barrier perform?**	**Why did the barrier fail?**	**How did the barrier affect accident?**
		c) A pre-job briefing was not performed with E1 and E2 within a month of performing the work. d) The RCT presence did not adhere to the RWP requirements.	c) The workers did not adhere to all of the requirements of the RWP. d) The RCT was not present as required by the RWP.
Personal Protective Equipment a) Second Pair of Gloves b) Respiratory Protection	Not used	a) Two pair of gloves were not worn by E1 and E2. b) Respirators were not utilized during the task, even though an airborne release had been postulated in the SAR.	a) Complications were experienced during the decontamination of E1 and E2 b) Lack of respirator resulted in an increase in the total intake by affected workers.
Implementation Plan in response to DNFSB 2000-1	Failed	The programmatic residues stored in room 201B were not included in the Implementation Plans for DNFSB 2000-1. The processing of this material was not included on any available schedule.	Actions were not taken to stabalize and adequately store the materials or to recover the Pu-238.
Surveillance Program	Failed	Surveillance of the packages in the room was not based on established criteria.	Issues associated with the packages in room 201B were not identified, documented, and anlayzed on a routine basis.
Lessons Learned	Failed	Multiple lessons learned opportunities were not communicated to the worker nor incorporated into the design of the storage packages or the surveillance program.	Managers and workers were not knowledgeable of or did not act upon lessons learned from precursor incidents at TA-55 and other DOE sites.

Acronyms

AB	Authorization Basis
AC	Administrative Controls
ALARA	as low as reasonably achievable
CAM	continuous air monitor
CSA	Criticality Safety Analysis
CEDE	committed effective dose equivalent
COA	Condition of Approval
DAC	derived air concentration
DAC-hrs	the integral of time and DAC
DF	design features
DP	Defense Programs
dpm	disintegrations per minute
DOD	Department of Defense
DSA	Documented Safety Analysis
EBE	Evaluation Basis Earthquake
EBF	Evaluation Basis Fire
ESH	Environment, Safety and Health
FAS	fixed air sampling
FOM	Facility Operations Manager
GC	General Counsel
HA	Hazard Analysis
HCl	hydrochloric acid
HEPA	high efficiency particulate air
HSR	Health, Safety and Radiation Division
ISI	in-service inspections
ISM	Integrated Safety Management
ISP	Integrated Surveillance Program
LAAO	Los Alamos Area Office (now known as LASO)
LANL	Los Alamos National Laboratory
LASO	Los Alamos Site Office (formerly known as LAAO)
LMSP	LANL Materials Stabilization Project
LPR	Laboratory Performance Requirement
MASS	Material Accountability and Safeguards Systems
MAR	material at risk
MIS	Material Identification and Surveillance
MRR	Material Release Radiological
MC&A	Materials Control and Accountability
MEO	mediated electrochemical oxidation
MPBB	maximum permissible body burden
MSO	molten salt oxidation
NDA	non-destructive assay
NNSA	National Nuclear Security Administration
NMT	Nuclear Materials Technology Division
NFT	Nuclear Filter Technology
PCM	personnel contamination monitor
PEP	Project Execution Plan
PFP	Plutonium Finishing Plant
PrHA	Process Hazard Analysis
PPE	Personnel Protective Equipment
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act
RCT	Radiological Control Technician
RFETS	Rocky Flats Environmental Technology Site
RTG	Radioisotope Thermoelectric Generator
RWP	Radiation Work Permit
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SD-HCPs	Short Duration Hazard Control Plans
SOP	Standard Operating Procedures
SNM	special nuclear material
SRS	Savannah River Site
TA	Technical Areas
TEDE	total effective dose equivalent
TID	tamper indicating device
TSR	Technical Safety Requirement
UC	University of California
USQ	unreviewed safety question
WAC	waste acceptance criteria
WGAT	Working Group Assessment Team
WI	Work Instructions
WIPP	Waste Isolation Pilot Project