BNFL Inc.

Record
① OB 3-15-05

RCA-03-007 Rev 1

IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

ADVANCED MIXED WASTE TREATMENT PROJECT

Investigation and Root Cause Analysis of the Fire in the TRU Waste Drum

BNFL INC.

24 September 2003

EXECUTIVE SUMMARY

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). Waste containers are currently being retrieved from under earth cover, where they have been stored approximately 30 years. Some of the containers show visible signs of potential overpressurization; these containers are vented using a commercially available remote drum punch. This punch is used elsewhere in both the chemical industry and in the DOE complex for venting drums of similar wastes with similar hazards. When the punching equipment was selected for manually venting waste drums, the selection was based on it being commercially available, spark resistant, and having been used in other areas of the DOE complex without incidence.

While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

The investigation of this event began immediately. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and BNFL employees familiar with incident investigation practices. On August 15, 2003, an outside incident investigation expert was asked to participate in the investigation process as the lead investigator.

The combustion event in the drum appears to have started the moment the drum was vented. The nature of the waste suggests hydrogen may have been present and, together with atmospheric oxygen or oxygen generated in the waste matrix, was ignited. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined.

Based on existing data and given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population of waste drums with a

potential for hydrogen generation. Therefore, the team has concluded that this event does not reveal any new or unforeseen phenomena regarding gas generation in this type of waste (IDC-D001).

Analysis Overview

The team has identified the direct cause, root cause, and contributing causes of the event. Based on the identified causes, the team has developed recommendations that are intended to minimize the potential for fires during the manual remote venting of drums. If such an event were to occur, the recommendations are also intended to improve the management of the event and to further mitigate the potential consequences associated with such an event.

In addition to the causes the team identified several observations related to the event. Although these issues did not directly lead to the events observed on August 13, 2003 they are included in the report as potential contributors to other possible loss scenarios.

Direct Cause

Equipment used in the remote drum punch venting activity lead to the generation of a low energy initiation source resulting in the ignition of a premixed hydrogen/oxidant mixture within the waste drum being vented.

Root Cause

Inadequate or Defective Design – DOE Cause Code 4B: The process of procuring, evaluating, and configuring the equipment selected for performing manual remote venting of waste drums in Building WMF-636 did not produce a final design that minimized the potential for ignition of combustible gases within a drum.

Contributing Causes

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for the implementation of changes and for work control at the AMWTP are not explicit regarding the appropriate method and level of rigor to be applied in regards to conducting a hazard assessment of the change.

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for work control at the AMWTP can in certain circumstances lead the user to a process for implementation of change, without a sufficient level of review and approval.

Observations

Observation #1 – The occurrence of an explosion/deflagration is identified in the safety basis documentation as an anticipated event for the facility; however, operational procedures regarded the event as an emergency, which required management of the event with the assistance of outside agencies and emergency response organizations.

Observation #2 – Procedures that direct drum venting using the remote drum punch system can be enhanced to more specifically provide instruction while drums are handled during segregation and subsequent venting.

Observation #3 – Approximately 72 hours after the event, a headspace gas sample indicated higher than atmospheric oxygen concentration. The team was not able to determine a mechanism to explain this observation.

Observation #4 – Even though fire was specifically identified as a potential hazard, a qualified Fire Protection subject matter expert was not consulted during the hazard assessments. This additional input could have resulted in identifying controls that would have minimized the potential for ignition.

Recommendations

Design Issues

1. Redesign and modify the remote drum punch system. Based on this redesign effort, include additional engineered controls for ignition control, fire/explosion mitigation, and worker safety. Controls such as grounding of the waste drum and associated equipment, enclosure/containment for an energetic release of pressure, and lid containment during the venting process should be considered. It is highly recommended that the redesign of the drum punching system include a review of the reference materials cited in this report in identifying the hazards and developing appropriate controls. This recommendation addresses the root cause of the event; Inadequate or Defective Design.
2. Review and approve the modified manual remote venting process using INST-CD&M-11.1.2, *Facility Modification Proposal Preparation,* (FMP) process. This recommendation addresses the root cause of the event; Inadequate or Defective Design.

Hazard Assessment

3. MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, and INST-CD&M-11.1.1, *Facility Modification Screening,* require the performance of a hazard assessment; however, they should be revised to specifically require conducting the assessment in accordance with INST-COPS-9.18.4, *Hazard Assessment.* This recommendation addresses the contributing cause of the event; Defective or Inadequate Procedure.

Procedures and Work Process

4. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include appropriate controls for worker safety during handling and setup of drums before the actual drum venting commences such as the use of a lid containment device, segregated storage, physical barriers, etc. This recommendation addresses observation #2.

5. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include the necessary engineering controls recommended in this report to reduce the potential for, and mitigate the effects of a single drum fire or explosion during the operations bounded by these operating instructions. This recommendation addresses observation #1.

6. Revise INST-COPS-9.18.2, *Permit to Work,* to provide a definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* and to include additional checks the user would be required to conduct to verify the work is not a change that must be processed through the FMP process. This recommendation addresses contributing cause; Defective or Inadequate Procedure.

7. Revise the requirements of the hazard assessment process, INST-COPS-9.18.4, *Hazard Assessment,* to ensure that personnel with a background in fire initiation and control mechanisms are included, as appropriate, on the assessment team when the potential for a drum fire/explosion exists. This recommendation addresses observation #4.

Event Response

8. Revise the facility emergency plans, operating procedures, and underlying safety basis documentation, such that the required actions for control of abnormal and infrequent situations of future events similar in magnitude to this event are bounded by the revised implementing procedures and do not require unnecessary activation of emergency response personnel and support organizations. This recommendation addresses observation #1.

TABLE OF CONTENTS

AMWTP FORM-1302

RCA Tracking Number: RCA-03-007
Location: AMWTP
Department: Operations
Date of Event: August 13, 2003
Source/Reference Document: Root Cause Analysis Handbook

Problem/Condition Description:

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). Waste containers are currently being retrieved from under earth cover, where they have been stored approximately 30 years. Some of the containers show visible signs of potential overpressurization; these containers are vented using a commercially available remote drum punch. This punch is used elsewhere in both the chemical industry and in the DOE complex for venting drums of similar wastes with similar hazards. While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

Analysis Summary:

The investigation team collected the data and summarized it in an event and causal factor chart and a fault tree. The investigation team used these tools to help identify the areas for which more data were necessary and to more clearly depict the relationship among key events leading to the event. The team acquired expert opinion regarding fire initiation from leading experts in the area of fire protection from both the DOE Complex and the Fire Protection Engineering industry, as well as acquiring technical input regarding waste characteristics, gas generation, and historical data related to the waste type involved in the fire from leading scientific personnel within the DOE Complex. The information obtained from these experts, in conjunction with the data surrounding the actual event formed the basis for this report. Using this information, the team determined the causes of the event and developed recommendations for facility management to consider. These recommendations focus on reducing or eliminating the key contributing factors; therefore, addressing these recommendations should help prevent recurrence of similar events.

RCA Team Members:

See Section 1.3, Table 1 of the attached report

Method and Level of RCRA Performed:

SOURCE™ Causal Factor Charting and Analysis – Graded Approach

Contributing Cause(s) of the Problem:

Defective or Inadequate Procedure

Root Cause of the Problem:

Inadequate or Defective Design

Applicable Cause Codes:

DOE Cause Code 4B - Inadequate or Defective Design

DOE Cause Code 2A - Defective or Inadequate Procedure

RCA Team Leader/Date: Lee N. Vanden Heuvel, ABS Consulting - September 24, 2003

for Elvin Dumas

QA Manager or Designee: Kay B Emanuel Date: 9-24-03

Department Manager: [signature] Date: 9/24/03

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of the investigation was to determine the cause of the fire, evaluate the effectiveness of existing operating instructions, emergency plans, and procedures applicable to the manual venting of TRU waste drums and to recommend actions to minimize the potential for recurrence of a similar event.

1.2 Event Synopsis

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). Waste containers are currently being retrieved from under earth cover, where they have been stored approximately 30 years. Some of the containers show visible signs of potential overpressurization; these containers are vented using a commercially available remote drum punch. This punch is used elsewhere in both the chemical industry and in the DOE complex for venting drums of similar wastes with similar hazards. While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

The investigation of this event began immediately. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and BNFL employees familiar with incident investigation practices. On August 15, 2003, an outside incident investigation expert was asked to participate in the investigation process as the lead investigator.

The combustion event in the drum appears to have started the moment the drum was vented. The nature of the waste suggests hydrogen may have been present and, together with atmospheric oxygen or oxygen generated in the waste matrix, was ignited. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined.

Based on existing data and given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population of waste drums with a potential for hydrogen generation. Therefore, the team has concluded that this event does not reveal any new or unforeseen phenomena regarding gas generation in this type of waste (IDC-D001).

1.3 Investigation Team

The investigation team began collecting data concerning the event shortly after it occurred on August 13, 2003. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and employees familiar with incident investigation practices. On August 15, 2003, an outside investigator was asked to participate in the investigation process as the lead investigator. The investigation team members are listed in Table 1.

Name	Organization	Title
Lee N. Vanden Heuvel	ABS Consulting	Lead Investigator
Mike Brooks	BNFL Inc.	Industrial Safety/Industrial Hygiene
Barbara Chaffin	BNFL Inc.	Operations Support
Mike Covington	BNFL Inc.	Shift Manager
Robin Rickman	BNFL Inc.	Operations Support Officer
Steve Thorne, P.E.	Bechtel BWXT LLC	Fire Marshal for INEEL

Table 1 Investigation Team

1.4 Investigation Methodology

The investigation team collected the data and summarized it in an event and causal factor chart and a fault tree. The investigation team used these tools to help identify the areas for which more data were necessary and to more clearly depict the relationship among key events leading to the event.

The team acquired expert opinion regarding fire initiation from leading experts in the area of fire protection from both the DOE Complex and the Fire Protection Engineering industry. As well as, acquiring technical input regarding waste characteristics, gas generation, and historical data related to the waste type involved in the fire from leading scientific personnel within the DOE Complex. The information obtained from these experts, in conjunction with the data surrounding the actual event formed the basis for this report. Using this information, the team determined the causes of the event and developed recommendations for facility management to consider. These recommendations focus on reducing or eliminating the key contributing factors; therefore, addressing these recommendations should help prevent recurrence of similar events.

This investigation report complies with all of the requirements of BNFL's event investigation program as described in MP-Q&SI-5.1, Rev. 1, *Investigation and Root Cause Analysis*. Prior to issuance, this report was peer reviewed by the subject matter experts listed in Table 2.

Name	Organization
Robert Holmes, Ph.D., Company Chief Scientist	BNFL Inc.
Craig Beyler, Ph.D.	Hughes Associates
Fred N. Carlson, Ph.D.	FN Carlson and Associates Inc.

Table 2 Peer Reviewers

2.0 WASTE DRUM BACKGROUND INFORMATION

The drum involved in the event, 55-gallon TRU waste drum IDRF07411511, contained first stage sludge, which was a wet sludge produced from aqueous process waste treatment operations at the Rocky Flats Plant (RFP). First stage sludge waste consists of immobilized materials generated from first-stage treatment operations in RFP Building 774. The treated materials consist of aqueous liquids from RFP Building 771 recovery operations that were made basic with sodium hydroxide to precipitate iron, magnesium, etc. This also carried down the relatively small amount of precipitate of plutonium (Pu) and americium (Am) hydrated oxides. The precipitate was filtered to produce a sludge.

Drum IDRF07411511 was configured similar to that shown in Figure 2. The drum was originally filled at Rocky Flats by first placing a rigid poly drum liner in the 55-gallon steel drum. Then, dry Portland cement was added to the bottom of the rigid poly drum liner. Next, a flexible polyethylene drum liner (plastic bag) was placed into the rigid poly drum. Dry Portland cement was added to the bottom of this liner. Next, another polyethylene drum liner (plastic bag) was placed in the barrel and the sludge placed into it. Once the drum was about 75% full, the inner polyethylene drum liner (plastic bag) was twisted closed and sealed with tape. Additional dry Portland cement was placed on top of the sludge bag and then the outer polyethylene drum liner (plastic bag) was twisted closed and taped. Next, the rigid drum liner lid was placed on the rigid drum liner in the drum. Finally, the metal drum lid was placed on the drum using a gasket and a sealing ring to seal the drum. The purpose of adding the Portland cement was to bind up any free liquid that may be released during storage and to harden the material within the drum. At the time of the event the drum contained no free liquids.

Most aqueous wastes from plutonium recovery operations in RFP Building 771 entered the first-stage of the Building 774 liquid waste processing facility by vacuum transfer through the process waste system. The Rocky Flats IDC-D001 waste drum involved in this event, IDRF07411511, was packaged in October 1978, about 25 years prior to the event. The most common waste streams that entered first-stage treatment for IDC-D001 were:

- Plutonium ion exchange column effluent
- Waste solutions (nitric, sulfuric, and hydrofluoric acids)
- Americium ion exchange column effluent
- Nitric acid distillate from feed evaporator
- Thiocyanate waste solution
- Water distillate from peroxide precipitation filtrate evaporator
- Caustic scrubber solution
- Steam condensate

The investigation team discovered that the drum involved in this event is known to fall into a population of drums that will or has the potential to exceed the wattage limit for the waste matrix, i.e., can produce radiolytic gases to a level of concern. Some 40% of this population is expected to exhibit this potential. The average fissile content of these drums, based on historical records is estimated to be approximately 5g Pu per drum and approximately 1.3g Am per drum.

The drum in question was assayed at 4.5g Pu and 1.2g Am. Thus, given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population with a potential for hydrogen generation. This event does not, therefore, reveal any new or unforeseen phenomena regarding gas generation.

Based on information provided, all drums of IDC-D001 could have a premixed hydrogen/oxygen environment. Even if the pressures are low and not obvious, a mere 4% hydrogen/air mixture results in a potentially explosive mixture. Therefore, based on the opinion of these professionals, the potential for this event exists for unvented waste drums with IDC-D001 codes assigned, and the complete elimination of the potential is not practical.

3.0 AMWTP PROCESS DESCRIPTION

The overall goal of the AMWTP is to prepare approximately 115,000 55-gallon drums and another 10,000 of other types of containers containing TRU mixed waste that is stored in various buildings on the RWMC site. The waste is retrieved from the current storage locations at the site. The contents of the containers are characterized so they can be certified for shipment to another site for long-term storage. This event took place at one of the site's storage buildings, the Transuranic Storage Area – Retrieval Enclosure (TSA-RE), also known as Building WMF-636 (Photograph 1), during the venting of the drum.

During normal waste container extraction activities, to ensure drum integrity, a visual inspection of each waste drum is completed at various steps in the procedure to determine if the container requires further management prior to additional handling. When a bulging drum is discovered the operating instructions require the operators to suspend all waste handling operations in the vicinity of the container, warn others in the area, place equipment in a safe and stable condition, evacuate personnel from the immediate area and secure access to protect against potential chemical dispersion from the container, notify appropriate supervision, attempt to determine the contents of the container by means of the Waste Tracking System (WTS) barcode number (if available) and any other pertinent information (from labels, etc.) that can be used to plan remedial actions. The operators are then directed by the operating instruction to develop and execute a course of action under the work control process or to remotely vent the drum with the remote drum punch system.

The activity involved in this event consists of venting the drum by punching a hole in the lid to relieve any internal pressure that may be present. Drum venting is performed to facilitate subsequent safe handling of the drum. After the drum has been retrieved from the storage array, the drum is placed on a plastic spill pallet for secondary containment. In this instance, the spill pallet was placed on top of a plastic sheet on the dirt floor of the TSA-RE. Figure 3 shows the overall layout of the equipment used in the process. The apparatus used for venting the drums is a portable, remote drum punch (Photograph 2). This device is commercially available and has been designed for drum venting and is used in other areas of the DOE complex. The remote drum punch has no electrical components. The system is actuated by nitrogen pressure. In preparation for venting a drum, the remote drum punch is placed on top of a drum. A vent tube and vent filter are connected to the remote drum punch to capture gases and particulate that are directed through the vent air hole located in the remote drum punch bit. In addition, a vacuum exhaust system with a HEPA filter is used to collect particulates that are not directed through the remote drum punch hose and filter from around the drum lid punch location. The remote drum punch is designed to penetrate the drum lid using a spark-resistant brass punch.

Personnel operating and observing the process are located just outside the TSA-RE, in a weather enclosure that is attached to the South side of the TSA-RE near the head end control room. The TSA-RE and weather enclosure are separated by a standard, commercial rollup door that contains four small windows. The windows allowed the personnel to observe the operations from about 30 feet away.

The remote drum punch operation is remotely controlled by an actuation control valve connected to a nitrogen bottle via a valve manifold. The indications of operation for the remote drum punch are nitrogen outlet pressure, and visual observation of the punch mechanism. Additionally, the area is automatically monitored by an alpha continuous air monitor (CAM) with alarm capabilities. There are no automatic recording devices for any system controls and indications.

The operation is controlled by a procedure, Operating Instruction INST-OI-09, Rev. 15, *Retrieval Enclosure Waste Container Extraction*. The activity is covered under section 4.12, "Abnormal and Infrequent Operation" subsection 4.12.4, "Bulging Waste Container", which provides a sequence of steps for venting bulging drums.

4.0 EVENT DESCRIPTION

4.1 Details of the Event

On the morning of August 13, 2003, a bulged 55-gallon waste drum with identification number IDRF07411511 was positioned in the TSA-RE facility. The drum was scheduled to undergo the venting procedure described in Section 3.0. The drum was placed about 30-feet inside and to the north of the door to the weather enclosure on a plastic spill pallet to contain any potential spills (Figure 3). Personnel had observed that this drum lid was bulging more than those previously processed at the AMWTP.

The spill pallet was positioned on a plastic sheet that was placed on the dirt floor that covers most of that portion of the TSA-RE (Figure 3 and Photograph 2). Preoperational checks of the venting equipment were performed, as delineated in procedure INST-OI-09. Once the drum was ready for venting, personnel moved outside the TSA-RE to the weather enclosure, closed the rollup door, and began the venting process. During the event, one individual was reading the procedure steps and another was repeating the instruction prior to performing the actions.

At approximately 8:15 AM, the operator actuated the remote drum punch. The remote drum punch began to move downward toward the drum lid. Once the remote drum punch contacted the lid, personnel observed that the remote drum punch took longer to punch through the lid on this drum than it had on previous drums. As the punch penetrated the drum lid, personnel reported hearing a 'louder than normal "pop"'. The visual observations made by five eyewitnesses are summarized below. These observations quickly followed the "pop" and are listed in the sequence in which the team concluded they occurred. The time period for the observations is estimated to be less than 20 seconds.

- **Dust rising about the drum.** Personnel observed dust suddenly rising above the top of the drum.
- **Deformation of drum lid.** Personnel observed that the drum lid rose up or "swelled" (Photograph 3).
- **Formation of additional holes in the drum lid.** Three small holes, appeared in the lid of the drum shortly after the drum lid rose up (Photograph 4).
- **Fire emanating from the holes in the drum.** Fire was observed to be emanating from all of the holes in the top of the drum. Personnel observed "arcs" of fire originating from the lid area of the drum, varying in color from bluish to orange and yellow and ranging in length from 4 inches to 14 inches. The flames were visible for a few seconds with estimates ranging from 2 to 15 seconds.
- **Drum Punch tool is canted.** Personnel observed that the drum punch tool canted but had remained attached to the drum (Photograph 5).

4.2 Emergency Response

Immediately following the observation of the flames, personnel evacuated the area and notified the INEEL fire department. At approximately 8:17 AM, the INEEL fire department received a report of a drum fire at the AMWTP. At approximately 8:18 AM, the INEEL fire department, consisting of Engine Company #1A, a Haz-Mat Unit, a Rescue Unit, and Chief's car departed the Central Facility Area (CFA) Fire Station and arrived at the AMWTP event scene at approximately 8:26 AM. The Battalion Chief established an on-scene incident command with BNFL personnel and conducted an incident "size-up". He was advised that the building had been evacuated, that no fire was coming out of the drum at this time, that all the building personnel had been accounted for, and that no radiological alarms had sounded. Firefighters entered the building and confirmed that no personnel were present and that no fire was evident. They noted that the drum was damaged and bulged.

At 8:42 AM, the AMWTP Emergency Coordinator declared an "Alert" level emergency. Upon being advised of the emergency declaration, Bechtel BWXT Idaho, LLC (BBWI) management directed the activation of the Emergency Operations Center (EOC), Public/Joint Information Center, and the Central Facilities Area Emergency Control Center to support response actions of the AMWTP per *[AMWTP] Tri-Party Memorandum of Agreement for BNFL Inc, Department of Energy and Bechtel BWXT Idaho LLC.*

An isolation zone was established around the building while emergency personnel were familiarized with the contents of the drum and prepared a re-entry plan. The drum was monitored by the fire department with thermal imaging. Thermal imaging conducted at approximately 9:18 AM indicated the upper region of the drum was clearly hotter than the lower region.

During the next 90 minutes, emergency management personnel verified the contents of the drum and completed the re-entry plan. At approximately 11:08 AM, re-entry was made with INEEL firefighters and one BNFL operator. They successfully retracted the remote drum punch from the drum. The fire department confirmed that the fire in the drum was no longer burning and that the drum had cooled to "normal" temperatures.

Upon exiting the building, one firefighter who was surveyed for potential radiological contamination had a count of 300 disintegrations per minute (DPM) alpha on one glove. Subsequent evaluation revealed the contamination to be due to radon gas and was determined to be unrelated to this event. The detection of Radon gas is a frequent occurrence in the TSA-RE.

The emergency event was terminated at approximately 11:15 AM.

5.0 POST EVENT ACTIVITIES

In the days immediately following the drum fire event, the drum lid was removed under controlled conditions and the drum and its contents were examined. Structural damage to the drum was evident in the lid and the drum bottom. The drum lid (Photograph 3) and drum bottom (Photograph 6) had deformed, as a result of the internal pressurization of the drum. Three small holes in the lid ranging from pinhole size to approximately 4 cm in length by 1 cm in width (Photograph 4) were identified in corroded areas of the lid. It was concluded that the pressurization of the drum created these holes in areas of the lid structurally weakened by external corrosion.

The interior of the drum was visually examined including the rigid liner. There were no indications of deformation or other physical damage to the rigid liner. The rigid liner lid had been displaced upwards yet it was still in contact with the rigid liner but canted on the top. There was no visible indication of drum wall rupture or deformation. Radiological smear samples taken on the external drum walls did not reveal any indication of external contamination.

A smoke soot line was visibly evident and was limited to the headspace volume of the drum (Photograph 7). The top of the waste drum polyethylene drum liner (plastic bag) used to line the drum had burned, decomposed, and melted exposing the layer of Portland cement used to cover the sludge-bearing waste material. The configuration of the solidified waste appeared to be unaffected. Based on the soot line markings, polyethylene drum liner (plastic bag) damage, and the absence of external drum contamination, it was concluded that the fire primarily occurred in the drum headspace and did not involve any of the radiological waste material.

6.0 EVALUATION OF CAUSE AND ORIGIN

6.1 Waste Drum Headspace Gases

Rocky Flats (RF) IDC-D001 waste is known to generate gases that could accumulate in the drum headspace. The RF IDC-D001 waste drum involved in this event was packaged in October 1978, about 25 years prior to the event. A report entitled, "*Idaho National Engineering Laboratory Code Assessment of the Rocky Flats Transuranic Waste*" (Wastren, 1995) reports headspace gas analyses for 13 drums containing First Stage Sludge, B774. These are reproduced in Figure 4. These gas analyses show elevated levels of hydrogen well in excess of the 4 % Lower Explosive Limit (LEL) for hydrogen as well as elevated levels of oxygen. Other flammable gases, notably hydrocarbons, were present but in concentrations below their respective LELs.

Based on the historical headspace data, it was concluded that the drum headspace could have contained a combustible mixture of hydrogen and oxygen at the time the drum was being vented.

6.2 Flammability and Ignition of Hydrogen

Mixtures of hydrogen with air, oxygen, or other oxidizers are highly flammable over a wide range of compositions. Flammability and explosion limits for hydrogen in dry air range from 4% LEL to 75% Upper Explosive Level (UEL) [Zalosh, 1995]. The energy required for ignition of hydrogen in air is 0.017 mJ (milliJoule) at 14.7 psi. Thus, low or weak energy, such as that caused by the discharge of static electricity from a human body, may be sufficient to cause ignition of a hydrogen/air mixture [NASA, 1997].

6.3 Potential Ignition Sources

Static Electricity

Static electricity could have been generated during the venting operation as a result of the operation of the vacuum exhaust. The operation of the vacuum exhaust could have produced a static charge on the vacuum hose. Since the drum was situated on a nonconductive surface (i.e., a plastic pallet) and was not bonded or grounded, a static charge produced at approximately the same time the drum was vented could have resulted in ignition of a hydrogen/air mixture being expelled through the vent hole produced by the punch. The flame could have then propagated back into the drum headspace causing a deflagration in the headspace.

Friction or Impact Sparks

Another ignition source is one resulting from friction or impact sparks. The remote drum punch used to vent the drum was powered by a nitrogen system using line pressures in the range of 150 psig. The punch is made of brass and is typically considered a spark resistant material. However, it is capable of producing friction or impact sparks. It was reported that a louder than normal "pop" was heard when the punch penetrated the drum. Thus, it is possible that the remote drum punch process resulted in a friction or impact spark, which served as the ignition source for the drum headspace combustion event.

Self Ignition

Hydrogen, with its low minimum ignition energy has been reported to self-ignite from static electricity [produced] as a result of leaking or venting [Cote, 1990].

6.4 Fire Consequences

"Ignition of a gas-air mixture in an unvented enclosure will usually result in a deflagration (i.e. flame propagation at subsonic speed away from the ignition site) [Zalosh, 2002]. As noted by Zalosh [2002], conservative estimates of burned gas temperature and composition can be obtained by assuming that combustion occurs adiabatically at constant volume. Calculated adiabatic constant-volume pressures resulting from hydrogen deflagrations (in air) can result in maximum pressures in the range of 8 atmospheres. Hydrogen mixtures at or near the lower flammable limit result in overpressures in the range of 3 atmospheres. In this event, the drum had been vented via the punch. Thus, the deflagration occurred in a "vented" condition, but was sufficient to produce overpressures (probably in the range of 3 atmospheres), which resulted in the deformation of the drum lid and bottom, as well as causing venting at the drum lid's weakest points.

The deflagration that occurred in the headspace resulted in flame temperatures at least as high as 980 °K, the adiabatic flame temperature for hydrogen at the Lower Flammability Limit [Beyler, 1988]. High density polyethylene has a thermal decomposition temperature of 506 °K [Beyler and Hirchler, 1995]. Thus, it was concluded that the headspace gas temperature produced by the deflagration would have been sufficient to cause ignition of the polyethylene drum liner (plastic bag).

Once ignited, the resulting polyethylene fire produced soot and other products of combustion. Consistent with vent flows associated with fire dynamics [Emmons, 2002], the heated products of combustion accumulated in the drum headspace and vented through the lid openings. The drum headspace had an approximate depth of 12 inches. When the polyethylene drum liner (plastic bag) ignited, the resulting decomposition process produced smoke, which quickly formed a smoke layer in the drum headspace. The smoke layer propagated quickly down the drum interior, depositing soot along the drum headspace wall and displacing any clean air in the drum headspace available for combustion. Consequently, the fire quickly became self-extinguishing as witnessed by personnel.

7.0 CONCLUSIONS

The event investigation revealed that a combustion event, characterized as a deflagration that generated overpressures, occurred within the headspace of the drum. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined. The flammable gases, believed to be hydrogen and oxygen in the headspace, deflagrated as a result of the low energy initiation source. The resulting fire produced overpressures, which deformed the drum bottom and lid and produced three small holes in the lid.

Interviews conducted by the investigation team revealed that data associated with the type of waste involved in the fire was available prior to the event. This data indicates that all drums of IDC-D001 have the potential to contain a combustible mixture of hydrogen/oxygen, even if the pressures are low and not obvious. Because a 4% hydrogen/air mixture results in a potentially explosive mixture, it is necessary that adequate controls are determined beforehand and put in place to ensure worker safety during the handling and manual venting of these types of waste drums.

Although the potential for ignition of the combustible gases could be reduced through the use of additional pre-determined controls, the investigation team believes, based on the opinions of professional fire protection personnel, that the possibility for complete elimination of the ignition potential cannot be realistically achieved and that it may not be practical to attempt to prevent all fires within a waste drum without extensive engineering controls involving elaborate and complicated systems and structures. Controls as recommended in this report, are intended to improve worker safety during the handling and subsequent venting of these drums and to minimize the potential for a fire. These additional controls, which include revising operating procedures and emergency plans to improve the management of a fire, treating a fire as an expected, although infrequent event. These improvements should place operational control of any recurrence of this type of event within the normal operational procedures and capabilities of the AMWTP and not require the activation of outside emergency response organizations.

8.0 DIRECT, ROOT, & CONTRIBUTING CAUSES

The first step in the investigation of the event was to analyze the available data to determine the causal factors and how each causal factor could occur. Next, the underlying reasons for each causal factor were identified to determine the management system weaknesses that caused or allowed the causal factors to occur. These underlying management system weaknesses are referred to as the contributing and root causes of the causal factors. Then, recommendations were developed to address each contributing cause and the root cause.

8.1 Direct Cause

Equipment used in the remote drum punch venting activity lead to the generation of a low energy initiation source resulting in the ignition of a premixed hydrogen/oxidant mixture, causing a deflagration within the waste drum being vented.

8.2 Root Cause

Inadequate or Defective Design – DOE Cause Code 4B: The process of procuring, evaluating, and configuring the equipment selected for performing manual remote venting of waste drums in Building WMF-636 did not produce a final design that minimized the potential for ignition of combustible gases within a drum.

When equipment was selected for manually venting waste drums, the selection was based on it being commercially available, spark resistant, and having been used in other areas of the DOE complex without incidence. For example, the drum punch tool selected was powered by nitrogen and not electricity and a brass punch was selected because it reduced the potential for sparking. However, other equipment and operational practices were not identified and implemented which could have further reduced the potential for sparking and in this respect, BNFL did not perform the most rigorous analysis. For example, the drum and tool were not electrically grounded. Instead they were placed on a plastic spill pallet that was placed on a plastic sheet; both items effectively isolate the drum and tool electrically from ground. A ventilation system was attached to the drum that rapidly drew air into a plastic hose. Each of these conditions has the potential for generating a static charge that has the potential to dissipate as a low energy initiation source.

Although it was known before this event that the possibility existed that an ignition source could be presented to combustible gases inside a waste drum during venting, the process by which the design of the manual remote drum punch device was determined, considered the punch as the only potential for introducing a source of ignition. Because BNFL did not undertake a formal design review of the procured equipment and its intended use, the specific potential for hydrogen ignition and all potential sources of ignition were not evaluated. Further the hazard potential for a hydrogen deflagration was not identified. Thus, the design process did not identify adequate control measures for reducing this potential hazard.

The design of the remote drum punching device may have met the requirements for a spark resistant tool but requirements for working with hydrogen and combustible gases should demand additional evaluation of ignition sources and determination of adequate controls to minimize the potential for all ignition sources that may be present and to mitigate the consequences of any ignition. Possible design features that were not considered include the use of an enclosure to mitigate the risk of contamination due to fire during the venting process. Additionally, there is industry developed personal protective equipment such as Tyvek suits impregnated with conductive fibers that are available and may have been appropriate to consider.

8.3 Contributing Causes

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for the implementation of changes and for work control at the AMWTP are not explicit regarding the appropriate method and level of rigor to be applied in regards to conducting a hazard assessment of the change.

Various management procedures and instructions direct hazard assessments to be performed based on the scope of work to be completed. These procedures and instructions include INST-COPS-9.18.2, *Permit to Work*, MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, INST-COPS-9.18.4, *Hazard Assessment*, and INST-CD&M-11.1.1, *Facility Modification Screening*.

Examples of the varying methods of hazard assessments that are allowed by these procedures include: 1) INST-COPS-9.18.2, *Permit to Work*, requires a review of the hazards associated with the work by one of several methods. These methods include either a review of INST-COPS-9.18.4, *Hazard Assessment*, or a review of Appendix A of INST-COPS-9.18.2, *Permit to Work*, coupled with the performance of a walkdown of the work area, or by convening a meeting of topic experts; 2) INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, requires only that the preparer of the proposal determine whether or not a hazard assessment is required, and if a hazard assessment is required, that it should be performed in accordance with INST-COPS-9.18.4, *Hazard Assessment*; 3) INST-CD&M-11.1.1, *Facility Modification Screening*, does not require any hazard assessment of the change; rather it requires only answering a series of yes/no questions regarding the effect the change will have. This procedure does; however, require the user to affect the change through other procedures such as the Facility Modification Proposal Preparation procedure or to use "...normal department procedures..."; departmental procedures which do require some level of hazard assessment be performed, 4) INST-COPS-9.18.4, *Hazard Assessment*, clearly states the requirements for performance of a hazard assessment when such assessment is required; this procedure does not contain any optional methods for performing the assessment.

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for work control at the AMWTP can in certain circumstances lead the user to a process for implementation of change, without a sufficient level of review and approval.

MP-CD&M-11.1, *Change Control,* very clearly defines a change at the AMWTP and it also clearly requires that all changes be processed in accordance with INST-CD&M-11.1.1, *Facility Modification Screening*. However, in the case of this event, the personnel involved felt the use of the manual remote drum punching device was not a change, rather they felt it was limited to the use of a new tool and as a result, personnel did not refer to the change control procedure. Rather, they defaulted directly to work control documentation (INST-COPS-9.18.2, *Permit to Work* [PTW]) to implement the use of what they understood to be a new tool.

Based on the wording in the PTW procedure, "*A PTW is required for each task performed at AMWTP, which is not addressed by routine operational instructions or is determined to be minor maintenance*", this procedure can appear to be the appropriate method for processing a change like the use of the remote drum punch system as a tool and would reinforce the decision personnel made that the mechanism wasn't necessarily a change. Based on this, personnel could easily assume that the PTW approach is appropriate. The PTW procedure does not provide guidance on when the more formal Facility Modification Proposal Preparation (FMP) process is required in lieu of the PTW process and because the PTW process procedure is silent regarding the implementation or definition of changes at the AMWTP, it is difficult to determine when the FMP process is appropriate.

When the equipment for the remote venting was procured and "installed", the change did not go through the FMP process outlined in CD&M-11.1.2. Because the FMP process was not used, personnel with the appropriate backgrounds and experience were not involved in the review and approval of the change. Changes that do go through the FMP process are reviewed by a group of senior managers. This review, performed by the Facility Change Group, ensures that a broad review of facility changes is performed. This team is composed of the Operations Manager and representatives from Environmental, Safety, and Health; Radiological Safety; Quality; Operations; Engineering; and Maintenance organizations. This additional review would also have been likely to identify the need for additional controls regarding this event.

Inclusion in INST-COPS-9.18.2, *Permit to Work,* of the definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* in addition to including other checks the user would be required to conduct to verify the work is not a change would provide an additional level of defense in depth to ensure changes are processed in accordance with the FMP process.

9.0 OBSERVATIONS

Four additional items were identified during the investigation that did not directly contribute to this event. However, they are potential contributors to other possible loss scenarios.

Observation #1 – The occurrence of an explosion/deflagration is identified in the safety basis documentation as an anticipated event for the facility; however, operational procedures regarded the event as an emergency, which required management of the event with the assistance of outside agencies and emergency response organizations.

The *AMWTP Documented Safety Analysis for Retrieval Operations* (DSA) discusses in several sections this event. The DSA, Section 3.3.2.3 describes the explosion/deflagration of volatile liquids or gases during handling in the characterization building as being representative of similar accidents that could occur in retrieval or during transport. This event has been analyzed with the most likely explosion that could occur during venting would be a small hydrogen flash with no consequences. The small hydrogen flash is an anticipated operational event that would neither challenge the enclosures nor result in an accidental release of either radioactive or hazardous material.

Although this event is analyzed as being an anticipated operational event, the AMWTP operating procedures and emergency plans do not adequately address the likeliness of this event such that the event can be adequately controlled through the use of operational procedures and instructions. As currently written, AMWTP procedures require unnecessary activation and response by outside agencies when the event occurred.

Observation #2 – Procedures that direct drum venting using the remote drum punch system can be enhanced to more specifically provide instruction while drums are handled during segregation and subsequent venting.

The current procedures (Operating Instructions INST-OI-09, Rev. 15, *Retrieval Enclosure Waste Container Extraction,* and INST-OI-11, Rev. 15, *Waste Container Handling)* include steps to inspect the condition of waste drums shortly after they are removed from the waste stack. If there is any visible bulging of the drum, the procedure requires the operators to suspend all waste handling operations in the vicinity of the container, warn others in the area, place equipment in a safe and stable condition, evacuate personnel from the immediate area and secure access, notify appropriate supervision, attempt to determine the contents of the container by means of the Waste Tracking System (WTS) barcode number (if available) and any other pertinent information (from labels, etc.) that can be used to plan remedial actions. The operators are then directed by the operating instruction to develop and execute a course of action under the work control process or to remotely vent the drum with the remote drum punch system. The process relies on visual indications to determine if the drum requires venting in WMF-636.

BNFL established a correlation between the internal pressure in the drum and the external indications of drum pressure based on historical data from the Department of Energy (Safety Notice Issue No. 93-01). This correlation allows personnel to estimate the internal drum pressure prior to handling and manually venting the drum. However, the hazards associated with the potential presence of hydrogen and oxygen in the headspaces of the drums have not been addressed in this procedure therefore there is no additional guidance in the procedure for properly and safely handling and segregating the suspect drums.

Observation #3 – Approximately 72 hours after the event, a headspace gas sample indicated higher than atmospheric oxygen concentration. The team was not able to determine a mechanism to explain this observation.

Approximately 72 hours after the event, a sample was taken of the headspace gas for drum IDRF07411511. Analysis of the sample indicated higher than atmospheric oxygen content (about 24%). Assuming the fire was self-extinguished because of oxygen depletion within the headspace of the drum, the oxygen concentration within the headspace would have been below atmospheric concentration (about 20%) immediately following the event. Therefore, in about 3 days, the oxygen concentration rose at least a few percent.

The team was not able to determine a mechanism to explain this observation. This may have health, safety, or environmental consequences for the processing steps that take place after the drums are vented.

Observation #4 – Even though fire was specifically identified as a potential hazard, a qualified Fire Protection subject matter expert was not consulted during the hazard assessments. This additional input could have resulted in identifying controls that would have minimized the potential for ignition.

Several hazard assessments were performed regarding the use of the remote drum punch device. The first assessment was completed in accordance with procedure INST-COPS-9.18.2, *Permit to Work*, prior to the initial use of the remote drum punch. A second assessment was completed in accordance with INST-COPS-9.18.4, *Hazard Assessment,* after the remote drum punch had been placed into service and used successfully a number of times. While the fire hazard and worker safety was specifically addressed during both of these reviews, the procedures being used to conduct the hazard assessments failed to cause the identification of additional controls that could have minimized the potential for ignition of the drum gases. INST-COPS-9.18.4, *Hazard Assessment,* requires that the overall makeup of each assessment team will be on a case-by-case basis as determined by the targeted assessment and that the team makeup must include Industrial Safety or Industrial Hygiene professionals and Operations, Radiological and Maintenance technicians who have involvement with the building, facility, and/or process being evaluated in addition to the discipline specific topic experts. There is no guidance in the procedures that would prompt the identification of "discipline specific topic experts".

Identification of other potential ignition sources by a qualified Fire Protection subject matter expert during the hazard assessments could have resulted in additional controls that would have minimized ignition sources and mitigated the deflagration/explosion hazard. Although it was recognized by the personnel involved in the hazard assessments that a "non-sparking" punch was required as a control, the procedures did not direct personnel to obtain an evaluation or screen by a qualified Fire Protection subject matter expert to determine appropriate controls to be applied to the task.

10.0 RECOMMENDATIONS

Recommendations include revisions to appropriate operating procedures, emergency plans, and the underlying safety basis documentation associated with drum fires during controlled venting operations. Operating procedures should be revised to include the appropriate engineering controls to reduce the potential for a drum fire/deflagration and to mitigate the consequences if a fire/deflagration does occur during remote drum venting operations. Revisions to emergency plans and underlying safety basis documentation should be considered, consistent with the level of work controls in place for the venting process (equipment and procedural controls).

Because outside emergency response did not contribute significantly to this event (i.e., there was no fire to extinguish, there was no release to the environment, and there were no injuries) the team believes that once the additional controls outlined in these recommendations are implemented, no additional outside emergency response should be required for a properly mitigated fire/deflagration in a single drum during the controlled venting process.

10.1 Recommendations Related to Direct, Contributing, and Root Causes

Design Issues

1. Redesign and modify the remote drum punch system. Based on this redesign effort, include additional engineered controls for ignition control, fire/deflagration mitigation, and worker safety. Controls such as grounding of the waste drum and associated equipment, enclosure/containment for an energetic release of pressure, and lid containment during the venting process should be considered. It is highly recommended that the redesign of the drum punching system include a review of the reference materials cited in this report in identifying the hazards and developing appropriate controls. This recommendation addresses the root cause of the event; Inadequate or Defective Design.
2. Review and approve the modified manual remote venting process using INST-CD&M-11.1.2, *Facility Modification Proposal Preparation,* (FMP) process. This recommendation addresses the root cause of the event; Inadequate or Defective Design.

Hazard Assessment

3. MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, and INST-CD&M-11.1.1, *Facility Modification Screening, require the performance of a hazard assessment; however, they should be revised to specifically require* conducting the assessment in accordance with INST-COPS-9.18.4, *Hazard Assessment.* This recommendation addresses the contributing cause of the event; Defective or Inadequate Procedure.

Procedures and Work Process

4. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include appropriate controls for worker safety during handling and setup of drums before the actual drum venting commences such as the use of a lid containment device, segregated storage, physical barriers, etc. This recommendation addresses observation #2.

5. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include the necessary engineering controls recommended in this report to reduce the potential for, and mitigate the effects of a single drum fire/deflagration or explosion during the operations bounded by these operating instructions. This recommendation addresses observation #1.

6. Revise INST-COPS-9.18.2, *Permit to Work,* to provide a definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* and to include additional checks the user would be required to conduct to verify the work is not a change that must be processed through the FMP process. This recommendation addresses contributing cause; Defective or Inadequate Procedure.

7. Revise the requirements of the hazard assessment process, INST-COPS-9.18.4, *Hazard Assessment,* to ensure that personnel with a background in fire protection engineering are included, as appropriate, on the assessment team when the potential for a fire hazard exists. This recommendation addresses observation #4.

Event Response

8. Revise the facility emergency plans, operating procedures, and underlying safety basis documentation, such that the required actions for control of abnormal and infrequent situations of future events similar in magnitude to this event are bounded by the revised implementing procedures and do not require unnecessary activation of emergency response personnel and support organizations. This recommendation addresses observation #1.

11.0 LESSONS LEARNED

1. Users of commercially available drum punching devices should ensure that the three potential initiation sources of friction or impact sparks, static electricity, and self ignition are considered fully in their particular environment to ensure that the equipment and operational practices have minimized the potential for the ignition of flammable gases, including the identification of any additional features or controls necessary to supplement the commercially available equipment.

2. When planning work activities associated with drums that are known to experience gas generation, the probability of a fire event should be considered. Based on safety basis documentation and information that is readily available within the DOE complex regarding the generation of combustible gases within waste drums, the flammability of those gases should be obtained and used to determine adequate controls to minimize fire/deflagration potential based on the predetermined probability of occurrence.

3. Facility operating procedures and emergency plans should be written consistent with the safety basis documentation regarding the probability of occurrence and significance of consequences to prevent an inappropriate level of activation of emergency response organizations. The probability of and consequences from an event should be considered when developing facility operating procedures to ensure the appropriate and required actions are included for facility personnel to perform; when such actions are clearly within the capabilities of the facility.

4. The process of developing and implementing work controls for new work activities benefits from performing a "what-if" analysis to evaluate the potential desired (and undesired) outcomes of a work task. This what-if evaluation of a new work activity results in the ability to adequately plan mitigation in the actual case of an event such as a fire/deflagration or equipment failure. Additionally, the process of evaluating new work activities benefits from considering the worst-case scenario of a given task. Defining the worst conditions of an activity allows for proper mitigation (in the form of engineering and administrative controls) necessary to reduce the severity of consequences in the actual case of an event such as a fire or equipment failure.

12.0 REFERENCES

1. Beyler and Hirchler, 1995. *Thermal Decomposition of Polymers. Society of Fire Protection Engineers, Fire Protection Handbook.* 2nd Edition, 1995. National Fire Protection Association, Quincy Mass.

2. Beyler, 1988. "Flammability Limits of Premixed and Diffusion Flames". SFPE Handbook of Fire Protection Engineering. 1988. National Fire Protection Association, Quincy, Mass.

3. Cote, 1990. *Industrial Fire Hazards Handbook*, Third Edition, Chapter 43. National Fire Protection Association, Quincy Mass.

4. DOE, 1993, Safety Notice 93-01, *Pressurized Drums, What Every Handler Should Know.*

5. DOE, 2003, *[AMWTP] Tri-Party Memorandum of Agreement for BNFL Inc, Department of Energy and Bechtel BWXT Idaho LLC,* DOE/ID-10520 Rev 3.

6. Emmons, 2002. "Vent Flows". SFPE Handbook of Fire Protection Engineering, 2002. National Fire Protection Association, Quincy, Mass.

7. NASA, 1997. *Safety Standard for Hydrogen and Hydrogen Systems, Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage and Transportation.* Effective date 1997. Office of Safety and Mission Assurance, Washington, DC 20546.

8. Wastren, 1995, *Idaho National Engineering Laboratory Code Assessment of the Rocky Flats Transuranic Waste*, INEL [INEEL] Report 95-0281.

9. Zalosh, 1995. *Explosion Protection*, Society of Fire Protection Engineers, Fire Protection Handbook. 2nd Edition, 1995. National Fire Protection Association, Quincy Mass.

13.0 APPENDICES

Appendix A, Figures

Appendix B, Photographs

APPENDIX A
FIGURES

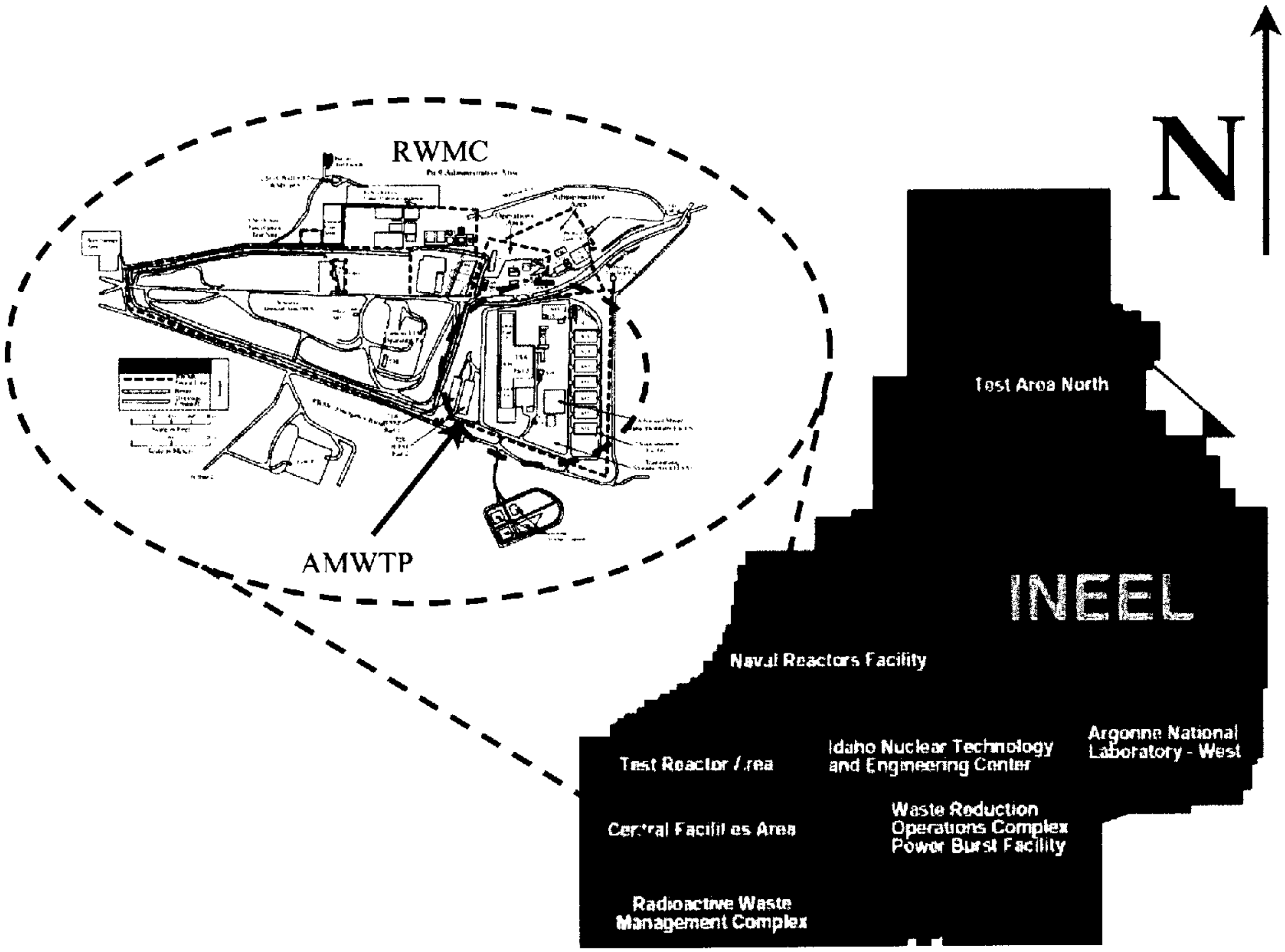


Figure 1: Map showing the location of the RWMC and AMWTP within the INEEL.

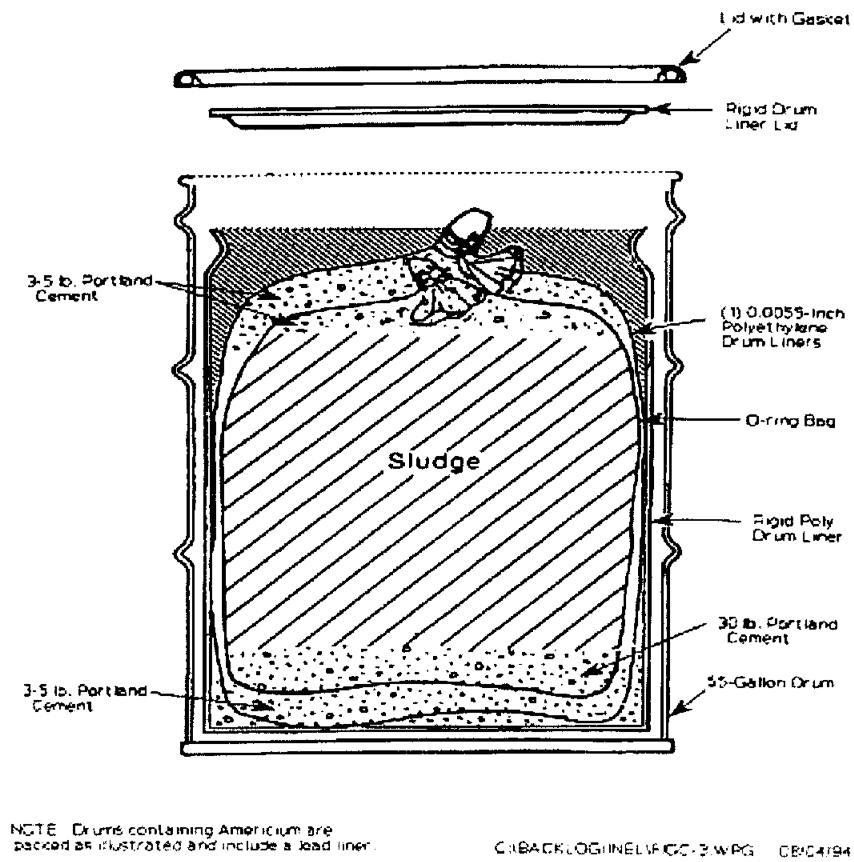


Figure 2: Typical packaging for drums with IDC Code D001, like the one involved in the event (Wastren, 1995).

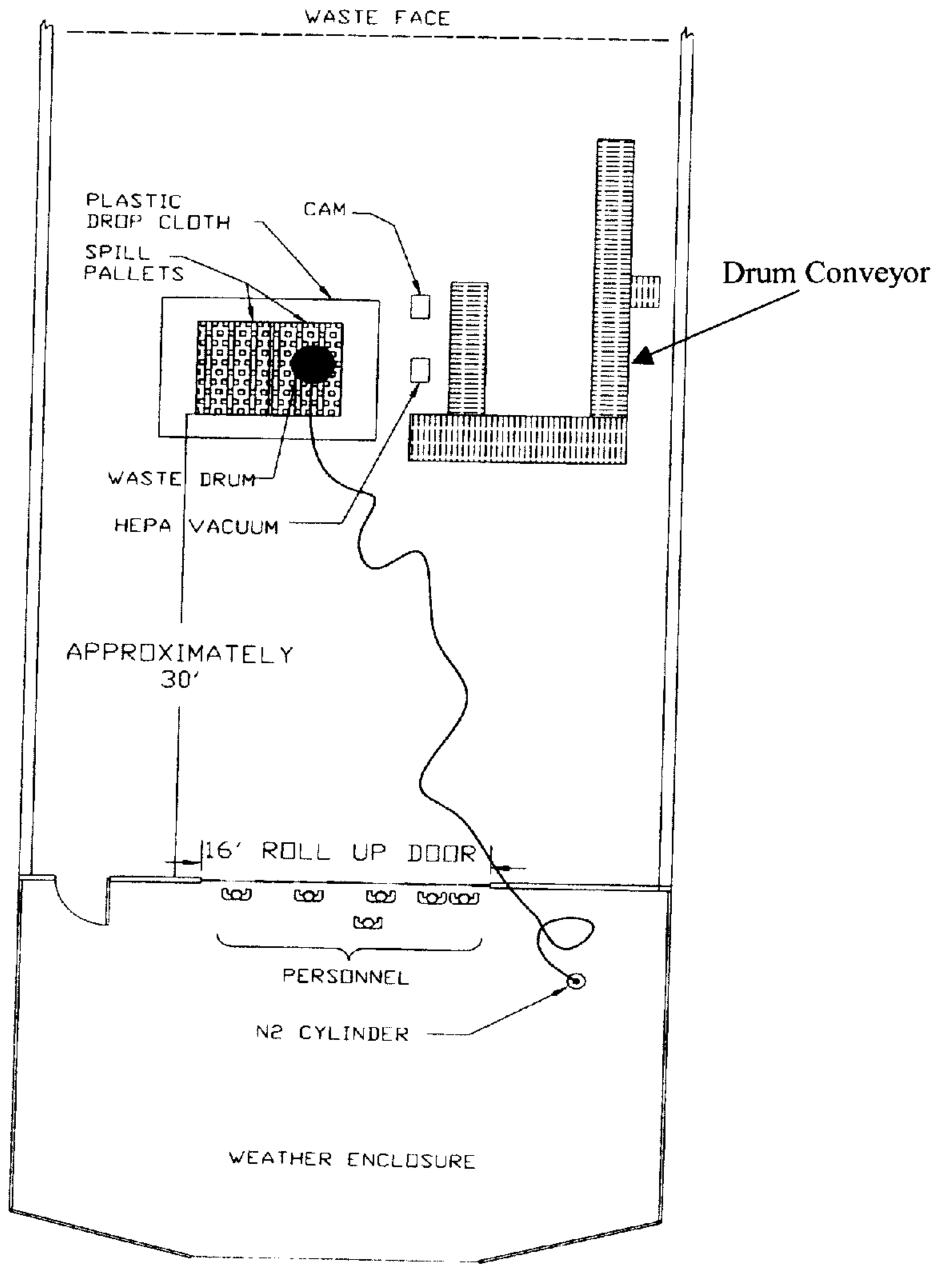


Figure 3: Plan view representing the configuration of the Remote Drum Punch equipment and personnel locations relative to the waste drum in WMF-636.

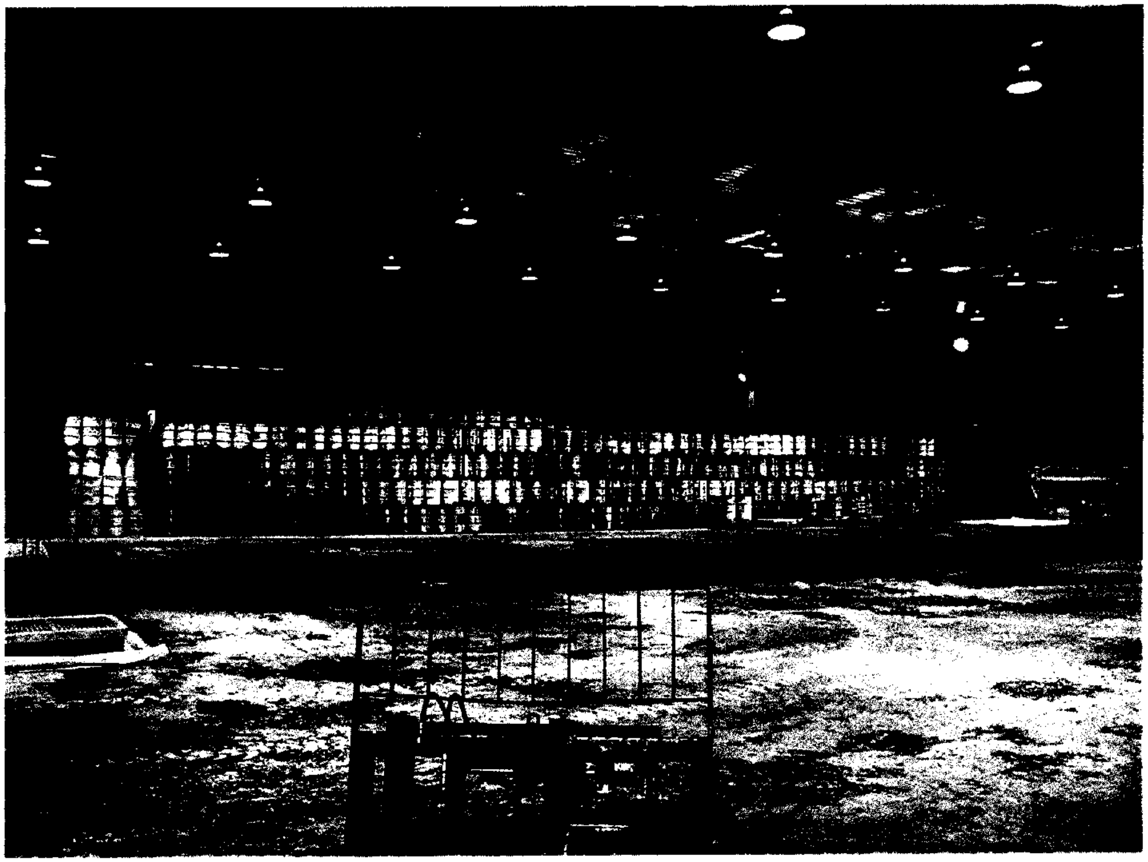
Table 3.1.1-11. Gas Sampling Results—Compositional Analysis (vol%).

Container ID.	Storage time (days)	Analytes									
		H_2	O_2	N_2	Ar	CO_2	CO	NO_X	Hydrocarbons (saturated)[1]	1,1,1-trichloro-ethane	Other Hydrocarbons[2]
7412-03121	144	0.03	21.1	77.5	0.94	0.02	—	—	0.07	0.29	0.04[a]
7412-03125	144	0.24	18.2	80.2	0.96	0.01	—	—	0.06	0.30	0.04[a]
7412-03127	144	0.18	18.1	79.9	0.95	0.02	—	—	0.13	0.58	0.12[a]
7412-03128	144	0.11	20.1	77.5	0.94	0.02	—	—	0.11	0.94	0.22[a]
											0.01[b]
7412-00483	1,089	1.2	21.1	76.4	0.90	0.09	—	—	0.35	—	—
7412-00636	975	5.30	15.6	77.4	0.96	0.11	—	—	0.24	0.38	—
7412-00766	904	2.02	21.0	75.5	0.95	0.11	—	—	0.16	0.24	—
7412-00797	902	0.78	3.87	94.0	1.2	—	—	—	0.11	—	—
741-12404	4,326	5.19	65.9	27.7	0.32	0.09	—	0.66	—	—	—
741-12794	4,205	4.12	46.8	48.0	0.58	0.14	—	0.27	—	0.05	0.04[c]
741-12858	4,213	11.7	35.7	51.3	0.61	0.14	—	0.46	—	0.04	0.01[c]
741-12387	4,304	1.85	30.9	66.2	0.79	0.09	—	0.15	—	0.03	0.01[c]
741-12795	4,203	11.0	73.4	14.5	0.17	0.13	—	0.63	—	0.94	0.02[c]
											0.01[b]

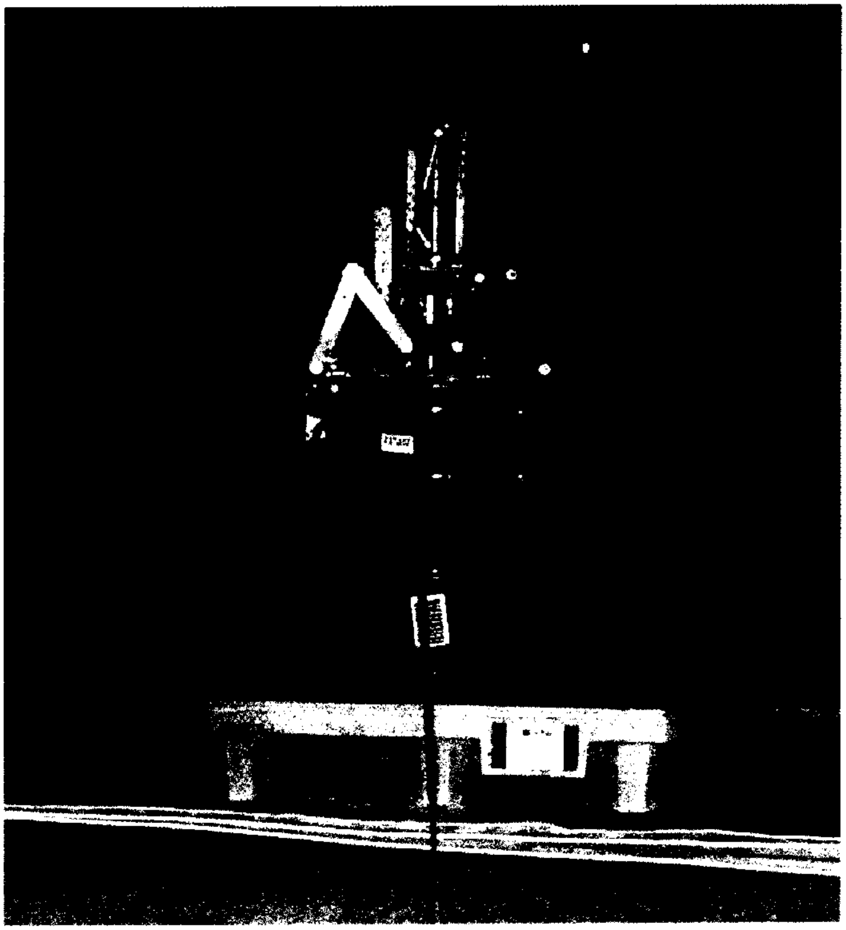
1. Saturated hydrocarbons—methane through propane.
2. Other hydrocarbons—as specified.
   a. Dichloromethane
   b. Carbon tetrachloride
   c. Trichloroethylene

Figure 4: Table showing the gas sampling results from 13 drums from the same IDC as the drum involved in the event (Wastren, 1995).

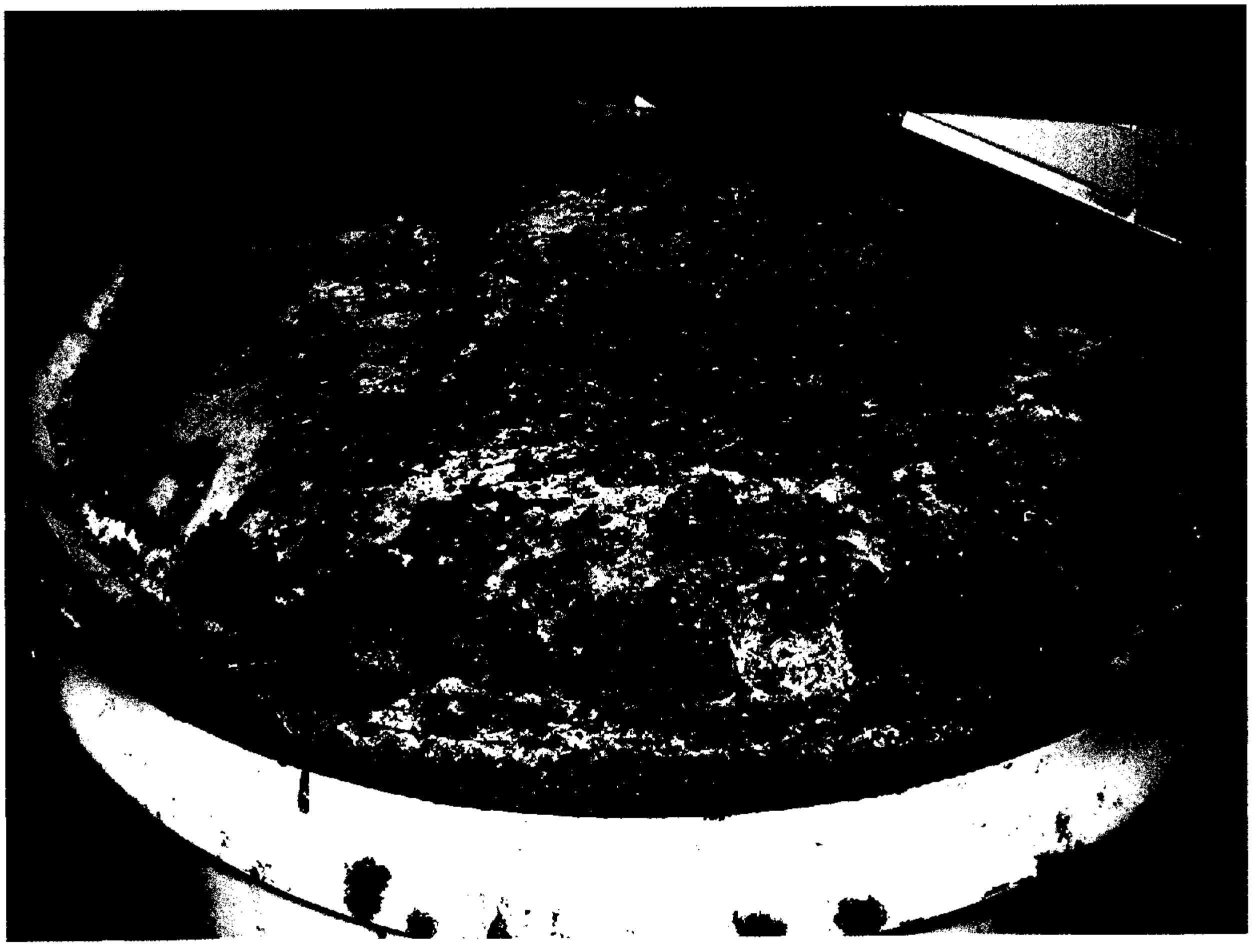
APPENDIX B
PHOTOGRAPHS



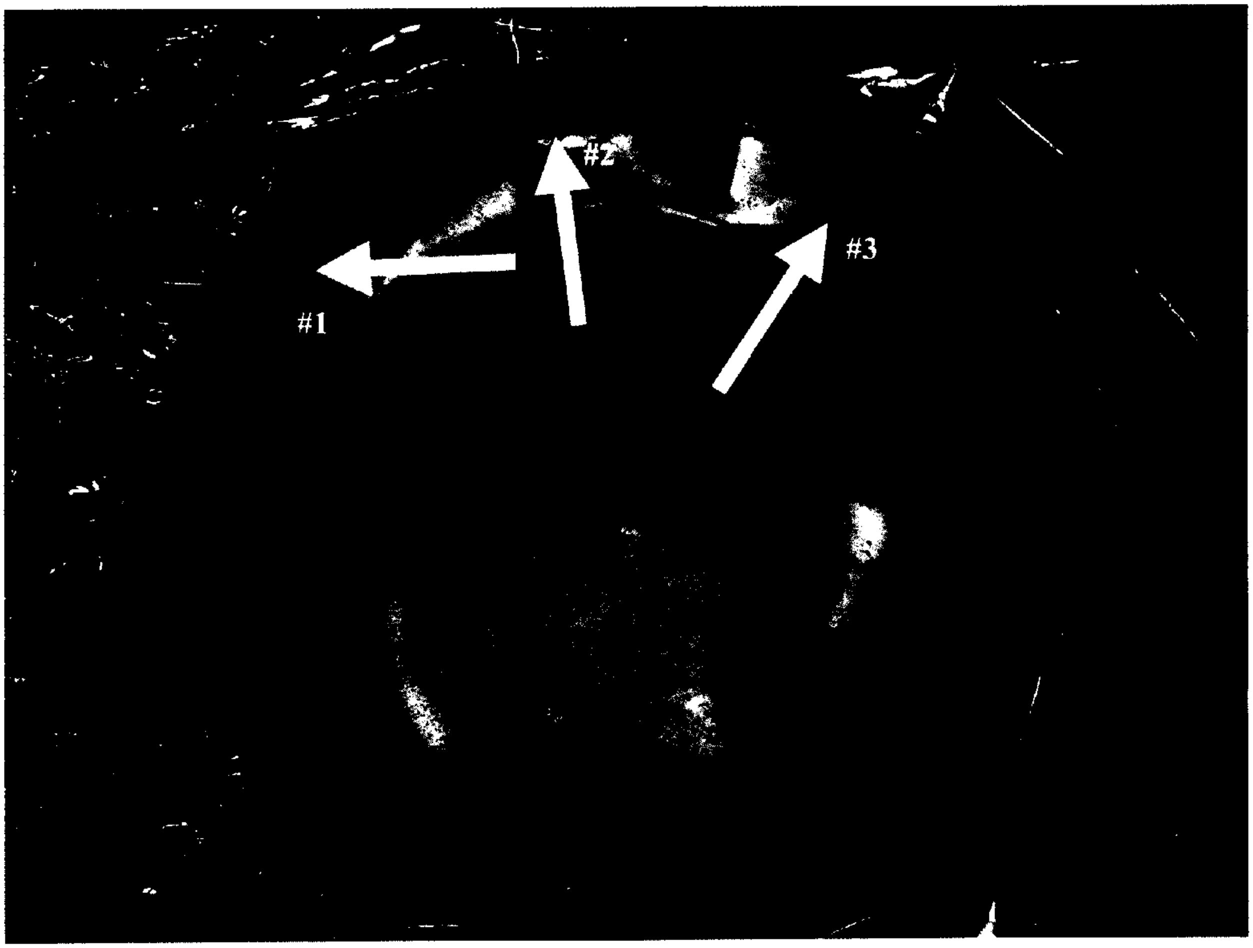
Photograph 1: Interior of the Transuranic Storage Area – Retrieval Area; the drum being vented during this event was off to the right of this picture.



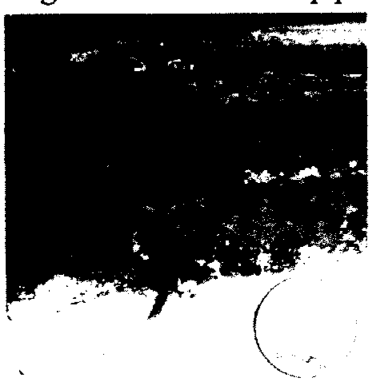
Photograph 2: Typical setup of the remote drum punch located on top of a typical 55-gallon waste drum showing the typical arrangement of the waste drum, plastic spill pallet, plastic sheeting and the remote drum punch tool.

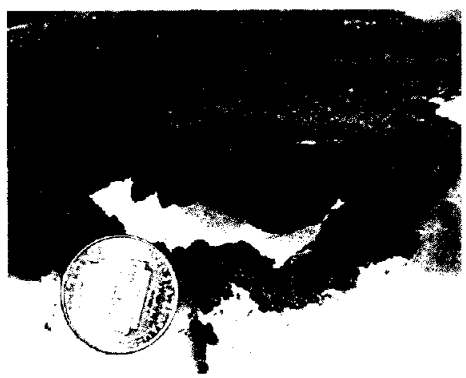


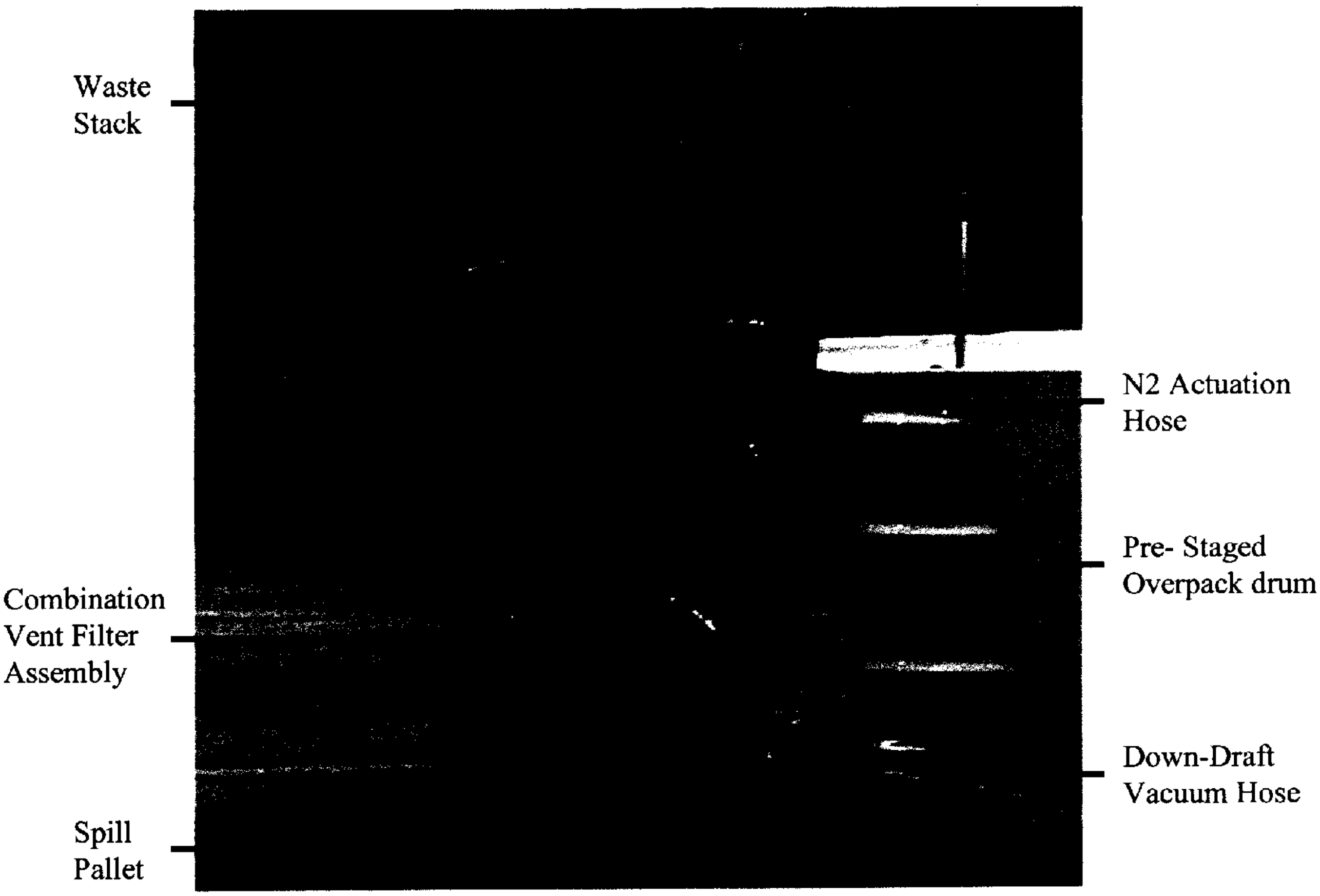
Photograph 3: Drum lid post-event, prior to removal, showing bulging.



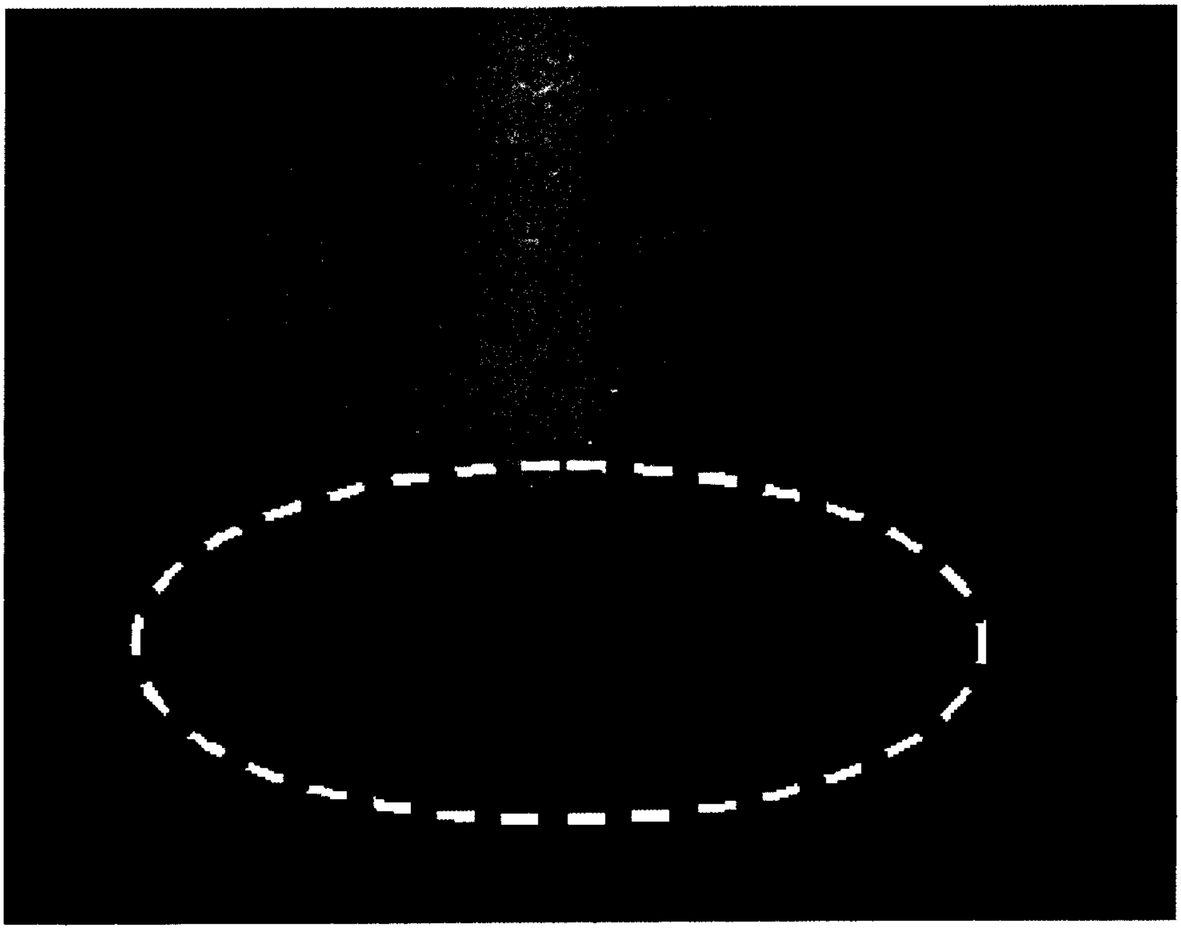
Photograph 4: Inside of the drum top showing the locations of the three holes that were formed during the event – Close-up photos are shown below.



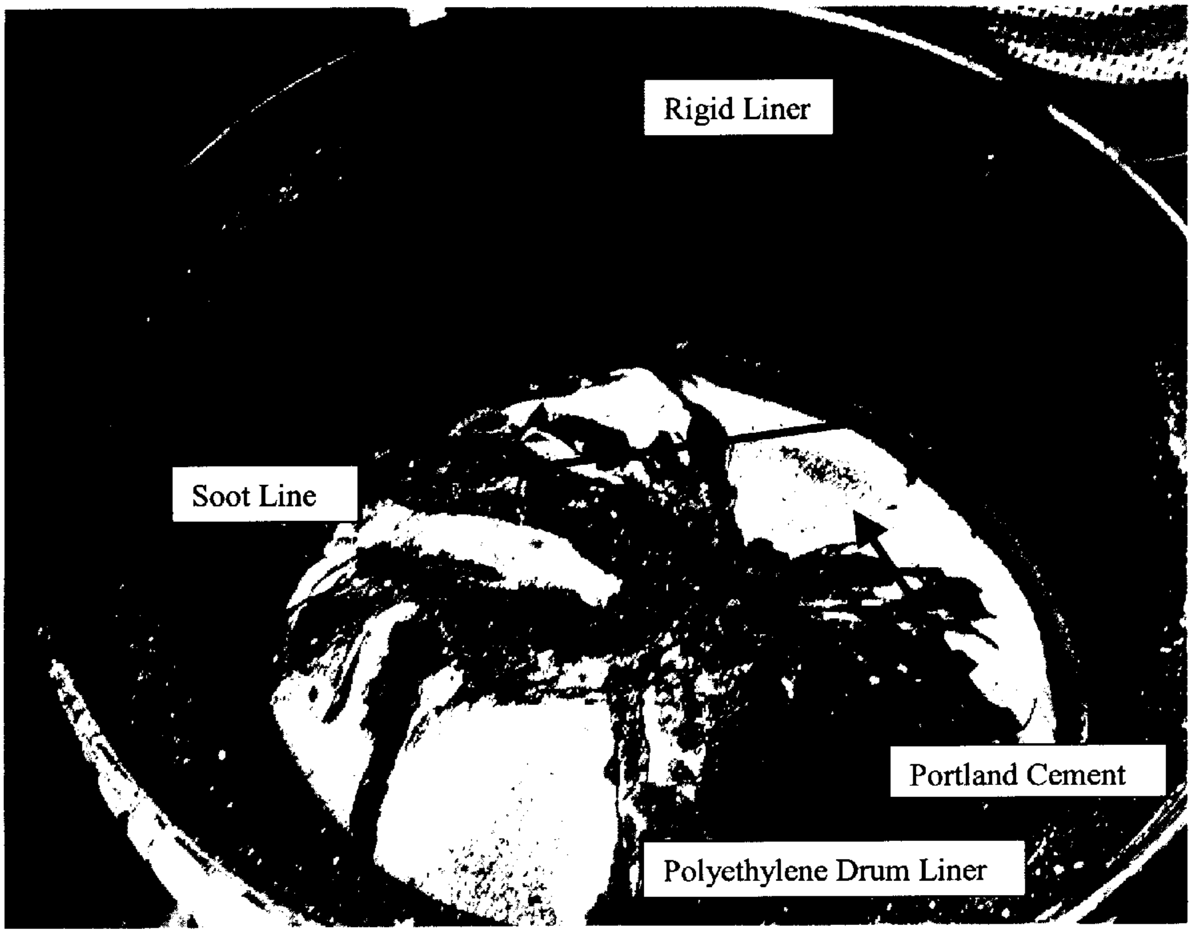




Photograph 5: Post event photo obtained during the event showing the affected drum and the Remote Drum Punch tool and other equipment associated with the drum venting. Note the left side of the Remote Drum Punch tool has been forced upward by the event.



Photograph 6: Lower end of the affected waste drum after the event. Note the lifting and tilting of the drum caused by the bottom of the drum bulging and protruding downward.



Photograph 7: Interior of the drum following the fire, showing the soot line about 12 inches below the rim of the drum.

BNFL Inc.

RCA-03-007

IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

ADVANCED MIXED WASTE TREATMENT PROJECT

Investigation and Root Cause Analysis of the Fire in the TRU Waste Drum

BNFL INC.

15 September 2003

EXECUTIVE SUMMARY

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

The investigation of this event began immediately. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and BNFL employees familiar with incident investigation practices. On August 15, 2003, an outside incident investigation expert was asked to participate in the investigation process as the lead investigator.

The combustion event in the drum appears to have started the moment the drum was vented. The nature of the waste suggests hydrogen may have been present and, together with atmospheric oxygen or oxygen generated in the waste matrix, was ignited. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined.

Based on existing data and given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population of waste drums with a potential for hydrogen generation. Therefore, the team has concluded that this event does not reveal any new or unforeseen phenomena regarding gas generation in this type of waste (IDC-D001).

Analysis Overview

The team has identified the direct cause, root cause, and contributing causes of the event. Based on the identified causes, the team has developed recommendations that are intended to minimize the potential for fires during the manual remote venting of drums. If such an event were to occur, the recommendations are also intended to improve the management of the event and to further mitigate the potential consequences associated with such an event.

In addition to the causes the team identified several observations related to the event. Although these issues did not directly lead to the events observed on August 13, 2003 they are included in the report as potential contributors to other possible loss scenarios.

Direct Cause

Equipment used in the remote drum punch venting activity lead to the generation of a low energy initiation source resulting in the ignition of a premixed hydrogen/oxidant mixture within the waste drum being vented.

Root Cause

Inadequate or Defective Design – DOE Cause Code 4B: The process of procuring, evaluating, and configuring the equipment selected for performing manual remote venting of waste drums in Building WMF-636 did not produce a final design that minimized the potential for ignition of combustible gases within a drum.

Contributing Causes

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for the implementation of changes and for work control at the AMWTP are not explicit regarding the appropriate method and level of rigor to be applied in regards to conducting a hazard assessment of the change.

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for work control at the AMWTP can in certain circumstances lead the user to a process for implementation of change, without a sufficient level of review and approval.

Observations

Observation #1 – The occurrence of an explosion/deflagration is identified in the safety basis documentation as an anticipated event for the facility; however, operational procedures regarded the event as an emergency, which required management of the event with the assistance of outside agencies and emergency response organizations.

Observation #2 – Procedures that direct drum venting using the remote drum punch system can be enhanced to more specifically provide instruction while drums are handled during segregation and subsequent venting.

Observation #3 – Approximately 72 hours after the event, a headspace gas sample indicated higher than atmospheric oxygen concentration. The team was not able to determine a mechanism to explain this observation.

Observation #4 – Even though fire was specifically identified as a potential hazard, a qualified Fire Protection subject matter expert was not consulted during the hazard assessments. This additional input could have resulted in identifying controls that would have minimized the potential for ignition.

Recommendations

Design Issues

1. Redesign and modify the remote drum punch system. Based on this redesign effort, include additional engineered controls for ignition control, fire/explosion mitigation, and worker safety. Controls such as grounding of the waste drum and associated equipment, enclosure/containment for an energetic release of pressure, and lid containment during the venting process should be considered. It is highly recommended that the redesign of the drum punching system include a review of the reference materials cited in this report in identifying the hazards and developing appropriate controls. This recommendation addresses the root cause of the event; Inadequate or Defective Design.
2. Review and approve the modified manual remote venting process using INST-CD&M-11.1.2, *Facility Modification Proposal Preparation,* (FMP) process. This recommendation addresses the root cause of the event; Inadequate or Defective Design.

Hazard Assessment

3. MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, and INST-CD&M-11.1.1, *Facility Modification Screening,* require the performance of a hazard assessment; however, they should be revised to specifically require conducting the assessment in accordance with INST-COPS-9.18.4, *Hazard Assessment.* This recommendation addresses the contributing cause of the event; Defective or Inadequate Procedure.

Procedures and Work Process

4. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include appropriate controls for worker safety during handling and setup of drums before the actual drum venting commences such as the use of a lid containment device, segregated storage, physical barriers, etc. This recommendation addresses observation #2.

5. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include the necessary engineering controls recommended in this report to reduce the potential for, and mitigate the effects of a single drum fire or explosion during the operations bounded by these operating instructions. This recommendation addresses observation #1.

6. Revise INST-COPS-9.18.2, *Permit to Work,* to provide a definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* and to include additional checks the user would be required to conduct to verify the work is not a change that must be processed through the FMP process. This recommendation addresses contributing cause; Defective or Inadequate Procedure.

7. Revise the requirements of the hazard assessment process, INST-COPS-9.18.4, *Hazard Assessment,* to ensure that personnel with a background in fire initiation and control mechanisms are included, as appropriate, on the assessment team when the potential for a drum fire/explosion exists. This recommendation addresses observation #4.

Event Response

8. Revise the facility emergency plans, operating procedures, and underlying safety basis documentation, such that the required actions for control of abnormal and infrequent situations of future events similar in magnitude to this event are bounded by the revised implementing procedures and do not require unnecessary activation of emergency response personnel and support organizations. This recommendation addresses observation #1.

TABLE OF CONTENTS

AMWTP FORM-1302

RCA Tracking Number: RCA-03-007
Location: AMWTP
Department: Operations
Date of Event: August 13, 2003
Source/Reference Document: Root Cause Analysis Handbook

Problem/Condition Description:

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

Analysis Summary:

The investigation team collected the data and summarized it in an event and causal factor chart and a fault tree. The investigation team used these tools to help identify the areas for which more data were necessary and to more clearly depict the relationship among key events leading to the event. The team acquired expert opinion regarding fire initiation from leading experts in the area of fire protection from both the DOE Complex and the Fire Protection Engineering industry. As well as acquiring technical input regarding waste characteristics, gas generation, and historical data related to the waste type involved in the fire from leading scientific personnel within the DOE Complex. The information obtained from these experts, in conjunction with the data surrounding the actual event formed the basis for this report. Using this information, the team determined the causes of the event and developed recommendations for facility management to consider. These recommendations focus on reducing or eliminating the key contributing factors; therefore, addressing these recommendations should help prevent recurrence of similar events.

RCA Team Members:

See Section 1.3, Table 1 of the attached report

Method and Level of RCRA Performed:

SOURCE™ Causal Factor Charting and Analysis – Graded Approach

Contributing Cause(s) of the Problem:

Defective or Inadequate Procedure

Root Cause of the Problem:

Inadequate or Defective Design

Applicable Cause Codes:

DOE Cause Code 4B - Inadequate or Defective Design

DOE Cause Code 2A - Defective or Inadequate Procedure

RCA Team Leader/Date: Lee N. Vanden Heuvel, ABS Consulting - September 15, 2003

QA Manager or Designee: [signature] Date: 9/18/03

Department Manager: [signature] Date: 9/18/03

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of the investigation was to determine the cause of the fire, evaluate the effectiveness of existing operating instructions, emergency plans, and procedures applicable to the manual venting of TRU waste drums and to recommend actions to minimize the potential for recurrence of a similar event.

1.2 Event Synopsis

On the morning of August 13, 2003, at approximately 8:15 AM, a brief fire occurred during venting of a 55-gallon waste drum at the Advanced Mixed Waste Treatment Project (AMWTP) operated by BNFL Inc. (BNFL), located at the Idaho National Engineering and Environmental Laboratory (INEEL). While in the process of venting drum DRF07411511, a bulged 55-gallon transuranic (TRU) waste drum, Item Description Code (IDC) D001 (IDC-D001 is explained later in the text of this report and should not be confused with RCRA waste code D001), a combustion event, characterized as a deflagration (fire) that generated overpressures, occurred within the headspace of the drum. The fire lasted several seconds and self-extinguished. The resulting pressurization further deformed the lid and produced three small holes (ranging from pin-hole sized to approximately 4 cm in length by 1 cm in width) in the lid of the drum. The drum lid remained in place and the structural integrity of the remainder of the drum remained intact (the only deformation observed was bulging of the drum lid and bottom). The solidified drum contents were not expelled. The configuration of the solidified TRU mixed waste in the drum appears to be unaffected. Further, there is evidence that the waste matrix was not involved in the fire (there was some damage to the polyethylene drum liners [plastic bags], but none of the waste was involved). The personnel evacuated the area and initiated emergency response actions in accordance with AMWTP procedures. No personnel injuries, spread of contamination, or release of contamination to the environment were associated with this event. Shortly after the event termination the drum was placed in an overpack container for storage.

The investigation of this event began immediately. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and BNFL employees familiar with incident investigation practices. On August 15, 2003, an outside incident investigation expert was asked to participate in the investigation process as the lead investigator.

The combustion event in the drum appears to have started the moment the drum was vented. The nature of the waste suggests hydrogen may have been present and, together with atmospheric oxygen or oxygen generated in the waste matrix, was ignited. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined.

Based on existing data and given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population of waste drums with a potential for hydrogen generation. Therefore, the team has concluded that this event does not reveal any new or unforeseen phenomena regarding gas generation in this type of waste (IDC-D001).

1.3 Investigation Team

The investigation team began collecting data concerning the event shortly after it occurred on August 13, 2003. The investigation team initially consisted of BNFL personnel familiar with the process, the INEEL Fire Marshal, and employees familiar with incident investigation practices. On August 15, 2003, an outside investigator was asked to participate in the investigation process as the lead investigator. The investigation team members are listed in Table 1.

Name	Organization	Title
Lee N. Vanden Heuvel	ABS Consulting	Lead Investigator
Mike Brooks	BNFL Inc.	Industrial Safety/Industrial Hygiene
Barbara Chaffin	BNFL Inc.	Operations Support
Mike Covington	BNFL Inc.	Shift Manager
Robin Rickman	BNFL Inc.	Operations Support Officer
Steve Thorne, P.E.	Bechtel BWXT LLC	Fire Marshal for INEEL

Table 1 Investigation Team

1.4 Investigation Methodology

The investigation team collected the data and summarized it in an event and causal factor chart and a fault tree. The investigation team used these tools to help identify the areas for which more data were necessary and to more clearly depict the relationship among key events leading to the event.

The team acquired expert opinion regarding fire initiation from leading experts in the area of fire protection from both the DOE Complex and the Fire Protection Engineering industry. As well as, acquiring technical input regarding waste characteristics, gas generation, and historical data related to the waste type involved in the fire from leading scientific personnel within the DOE Complex. The information obtained from these experts, in conjunction with the data surrounding the actual event formed the basis for this report. Using this information, the team determined the causes of the event and developed recommendations for facility management to consider. These recommendations focus on reducing or eliminating the key contributing factors; therefore, addressing these recommendations should help prevent recurrence of similar events.

This investigation report complies with all of the requirements of BNFL's event investigation program as described in MP-Q&SI-5.1, Rev. 1, *Investigation and Root Cause Analysis*. Prior to issuance, this report was peer reviewed by the subject matter experts listed in Table 2.

Name	Organization
Robert Holmes, Ph.D., Company Chief Scientist	BNFL Inc.
Craig Beyler, Ph.D.	Hughes Associates
Fred N. Carlson, Ph.D.	FN Carlson and Associates Inc.

Table 2 Peer Reviewers

2.0 WASTE DRUM BACKGROUND INFORMATION

The drum involved in the event, 55-gallon TRU waste drum IDRF07411511, contained first stage sludge, which was a wet sludge produced from aqueous process waste treatment operations at the Rocky Flats Plant (RFP). First stage sludge waste consists of immobilized materials generated from first-stage treatment operations in RFP Building 774. The treated materials consist of aqueous liquids from RFP Building 771 recovery operations that were made basic with sodium hydroxide to precipitate iron, magnesium, etc. This also carried down the relatively small amount of precipitate of plutonium (Pu) and americium (Am) hydrated oxides. The precipitate was filtered to produce a sludge.

Drum IDRF07411511 was configured similar to that shown in Figure 2. The drum was originally filled at Rocky Flats by first placing a rigid poly drum liner in the 55-gallon steel drum. Then, dry Portland cement was added to the bottom of the rigid poly drum liner. Next, a flexible polyethylene drum liner (plastic bag) was placed into the rigid poly drum. Dry Portland cement was added to the bottom of this liner. Next, another polyethylene drum liner (plastic bag) was placed in the barrel and the sludge placed into it. Once the drum was about 75% full, the inner polyethylene drum liner (plastic bag) was twisted closed and sealed with tape. Additional dry Portland cement was placed on top of the sludge bag and then the outer polyethylene drum liner (plastic bag) was twisted closed and taped. Next, the rigid drum liner lid was placed on the rigid drum liner in the drum. Finally, the metal drum lid was placed on the drum using a gasket and a sealing ring to seal the drum. The purpose of adding the Portland cement was to bind up any free liquid that may be released during storage and to harden the material within the drum. At the time of the event the drum contained no free liquids.

Most aqueous wastes from plutonium recovery operations in RFP Building 771 entered the first-stage of the Building 774 liquid waste processing facility by vacuum transfer through the process waste system. The Rocky Flats IDC-D001 waste drum involved in this event, IDRF07411511, was packaged in October 1978, about 25 years prior to the event. The most common waste streams that entered first-stage treatment for IDC-D001 were:

- Plutonium ion exchange column effluent
- Waste solutions (nitric, sulfuric, and hydrofluoric acids)
- Americium ion exchange column effluent
- Nitric acid distillate from feed evaporator
- Thiocyanate waste solution
- Water distillate from peroxide precipitation filtrate evaporator
- Caustic scrubber solution
- Steam condensate

The investigation team discovered that the drum involved in this event is known to fall into a population of drums that will or has the potential to exceed the wattage limit for the waste matrix, i.e., can produce radiolytic gases to a level of concern. Some 40% of this population is expected to exhibit this potential. The average fissile content of these drums, based on historical records is estimated to be approximately 5g Pu per drum and approximately 1.3g Am per drum.

The drum in question was assayed at 4.5g Pu and 1.2g Am. Thus, given the uncertainties in assay and estimates, this drum might have been expected, based on existing knowledge, to be within the population with a potential for hydrogen generation. This event does not, therefore, reveal any new or unforeseen phenomena regarding gas generation.

Based on information provided, all drums of IDC-D001 could have a premixed hydrogen/oxygen environment. Even if the pressures are low and not obvious, a mere 4% hydrogen/air mixture results in a potentially explosive mixture. Therefore, based on the opinion of these professionals, the potential for this event exists for unvented waste drums with IDC-D001 codes assigned, and the complete elimination of the potential is not practical.

3.0 AMWTP PROCESS DESCRIPTION

The overall goal of the AMWTP is to prepare approximately 115,000 55-gallon drums and another 10,000 of other types of containers containing TRU mixed waste that is stored in various buildings on the RWMC site. The waste is retrieved from the current storage locations at the site. The contents of the containers are characterized so they can be certified for shipment to another site for long-term storage. This event took place at one of the site's storage buildings, the Transuranic Storage Area – Retrieval Enclosure (TSA-RE), also known as Building WMF-636 (Photograph 1), during the venting of the drum.

During normal waste container extraction activities, to ensure drum integrity, a visual inspection of each waste drum is completed at various steps in the procedure to determine if the container requires further management prior to additional handling. When a bulging drum is discovered the operating instructions require the operators to suspend all waste handling operations in the vicinity of the container, warn others in the area, place equipment in a safe and stable condition, evacuate personnel from the immediate area and secure access to protect against potential chemical dispersion from the container, notify appropriate supervision, attempt to determine the contents of the container by means of the Waste Tracking System (WTS) barcode number (if available) and any other pertinent information (from labels, etc.) that can be used to plan remedial actions. The operators are then directed by the operating instruction to develop and execute a course of action under the work control process or to remotely vent the drum with the remote drum punch system.

The activity involved in this event consists of venting the drum by punching a hole in the lid to relieve any internal pressure that may be present. Drum venting is performed to facilitate subsequent safe handling of the drum. After the drum has been retrieved from the storage array, the drum is placed on a plastic spill pallet for secondary containment. In this instance, the spill pallet was placed on top of a plastic sheet on the dirt floor of the TSA-RE. Figure 3 shows the overall layout of the equipment used in the process. The apparatus used for venting the drums is a portable, remote drum punch (Photograph 2). This device is commercially available and has been designed for drum venting and is used in other areas of the DOE complex. The remote drum punch has no electrical components. The system is actuated by nitrogen pressure. In preparation for venting a drum, the remote drum punch is placed on top of a drum. A vent tube and vent filter are connected to the remote drum punch to capture gases and particulate that are directed through the vent air hole located in the remote drum punch bit. In addition, a vacuum exhaust system with a HEPA filter is used to collect particulates that are not directed through the remote drum punch hose and filter from around the drum lid punch location. The remote drum punch is designed to penetrate the drum lid using a spark-resistant brass punch.

Personnel operating and observing the process are located just outside the TSA-RE, in a weather enclosure that is attached to the South side of the TSA-RE near the head end control room. The TSA-RE and weather enclosure are separated by a standard, commercial rollup door that contains four small windows. The windows allowed the personnel to observe the operations from about 30 feet away.

The remote drum punch operation is remotely controlled by an actuation control valve connected to a nitrogen bottle via a valve manifold. The indications of operation for the remote drum punch are nitrogen outlet pressure, and visual observation of the punch mechanism. Additionally, the area is automatically monitored by an alpha continuous air monitor (CAM) with alarm capabilities. There are no automatic recording devices for any system controls and indications.

The operation is controlled by a procedure, Operating Instruction INST-OI-09, Rev. 15, *Retrieval Enclosure Waste Container Extraction*. The activity is covered under section 4.12, "Abnormal and Infrequent Operation" subsection 4.12.4, "Bulging Waste Container", which provides a sequence of steps for venting bulging drums.

4.0 EVENT DESCRIPTION

4.1 Details of the Event

On the morning of August 13, 2003, a bulged 55-gallon waste drum with identification number IDRF07411511 was positioned in the TSA-RE facility. The drum was scheduled to undergo the venting procedure described in Section 3.0. The drum was placed about 30-feet inside and to the north of the door to the weather enclosure on a plastic spill pallet to contain any potential spills (Figure 3). Personnel had observed that this drum lid was bulging more than those previously processed at the AMWTP.

The spill pallet was positioned on a plastic sheet that was placed on the dirt floor that covers most of that portion of the TSA-RE (Figure 3 and Photograph 2). Preoperational checks of the venting equipment were performed, as delineated in procedure INST-OI-09. Once the drum was ready for venting, personnel moved outside the TSA-RE to the weather enclosure, closed the rollup door, and began the venting process. During the event, one individual was reading the procedure steps and another was repeating the instruction prior to performing the actions.

At approximately 8:15 AM, the operator actuated the remote drum punch. The remote drum punch began to move downward toward the drum lid. Once the remote drum punch contacted the lid, personnel observed that the remote drum punch took longer to punch through the lid on this drum than it had on previous drums. As the punch penetrated the drum lid, personnel reported hearing a 'louder than normal "pop"'. The visual observations made by five eyewitnesses are summarized below. These observations quickly followed the "pop" and are listed in the sequence in which the team concluded they occurred. The time period for the observations is estimated to be less than 20 seconds.

- **Dust rising about the drum.** Personnel observed dust suddenly rising above the top of the drum.
- **Deformation of drum lid.** Personnel observed that the drum lid rose up or "swelled" (Photograph 3).
- **Formation of additional holes in the drum lid.** Three small holes, appeared in the lid of the drum shortly after the drum lid rose up (Photograph 4).
- **Fire emanating from the holes in the drum.** Fire was observed to be emanating from all of the holes in the top of the drum. Personnel observed "arcs" of fire originating from the lid area of the drum, varying in color from bluish to orange and yellow and ranging in length from 4 inches to 14 inches. The flames were visible for a few seconds with estimates ranging from 2 to 15 seconds.
- **Drum Punch tool is canted.** Personnel observed that the drum punch tool canted but had remained attached to the drum (Photograph 5).

4.2 Emergency Response

Immediately following the observation of the flames, personnel evacuated the area and notified the INEEL fire department. At approximately 8:17 AM, the INEEL fire department received a report of a drum fire at the AMWTP. At approximately 8:18 AM, the INEEL fire department, consisting of Engine Company #1A, a Haz-Mat Unit, a Rescue Unit, and Chief's car departed the Central Facility Area (CFA) Fire Station and arrived at the AMWTP event scene at approximately 8:26 AM. The Battalion Chief established an on-scene incident command with BNFL personnel and conducted an incident "size-up". He was advised that the building had been evacuated, that no fire was coming out of the drum at this time, that all the building personnel had been accounted for, and that no radiological alarms had sounded. Firefighters entered the building and confirmed that no personnel were present and that no fire was evident. They noted that the drum was damaged and bulged.

At 8:42 AM, the AMWTP Emergency Coordinator declared an "Alert" level emergency. Upon being advised of the emergency declaration, Bechtel BWXT Idaho, LLC (BBWI) management directed the activation of the Emergency Operations Center (EOC), Public/Joint Information Center, and the Central Facilities Area Emergency Control Center to support response actions of the AMWTP per *[AMWTP] Tri-Party Memorandum of Agreement for BNFL Inc, Department of Energy and Bechtel BWXT Idaho LLC.*

An isolation zone was established around the building while emergency personnel were familiarized with the contents of the drum and prepared a re-entry plan. The drum was monitored by the fire department with thermal imaging. Thermal imaging conducted at approximately 9:18 AM indicated the upper region of the drum was clearly hotter than the lower region.

During the next 90 minutes, emergency management personnel verified the contents of the drum and completed the re-entry plan. At approximately 11:08 AM, re-entry was made with INEEL firefighters and one BNFL operator. They successfully retracted the remote drum punch from the drum. The fire department confirmed that the fire in the drum was no longer burning and that the drum had cooled to "normal" temperatures.

Upon exiting the building, one firefighter who was surveyed for potential radiological contamination had a count of 300 disintegrations per minute (DPM) alpha on one glove. Subsequent evaluation revealed the contamination to be due to radon gas and was determined to be unrelated to this event. The detection of Radon gas is a frequent occurrence in the TSA-RE.

The emergency event was terminated at approximately 11:15 AM.

5.0 POST EVENT ACTIVITIES

In the days immediately following the drum fire event, the drum lid was removed under controlled conditions and the drum and its contents were examined. Structural damage to the drum was evident in the lid and the drum bottom. The drum lid (Photograph 3) and drum bottom (Photograph 6) had deformed, as a result of the internal pressurization of the drum. Three small holes in the lid ranging from pinhole size to approximately 4 cm in length by 1 cm in width (Photograph 4) were identified in corroded areas of the lid. It was concluded that the pressurization of the drum created these holes in areas of the lid structurally weakened by external corrosion.

The interior of the drum was visually examined including the rigid liner. There were no indications of deformation or other physical damage to the rigid liner. The rigid liner lid had been displaced upwards yet it was still in contact with the rigid liner but canted on the top. There was no visible indication of drum wall rupture or deformation. Radiological smear samples taken on the external drum walls did not reveal any indication of external contamination.

A smoke soot line was visibly evident and was limited to the headspace volume of the drum (Photograph 7). The top of the waste drum polyethylene drum liner (plastic bag) used to line the drum had burned, decomposed, and melted exposing the layer of Portland cement used to cover the sludge-bearing waste material. The configuration of the solidified waste appeared to be unaffected. Based on the soot line markings, polyethylene drum liner (plastic bag) damage, and the absence of external drum contamination, it was concluded that the fire primarily occurred in the drum headspace and did not involve any of the radiological waste material.

6.0 EVALUATION OF CAUSE AND ORIGIN

6.1 Waste Drum Headspace Gases

Rocky Flats (RF) IDC-D001 waste is known to generate gases that could accumulate in the drum headspace. The RF IDC-D001 waste drum involved in this event was packaged in October 1978, about 25 years prior to the event. A report entitled, "*Idaho National Engineering Laboratory Code Assessment of the Rocky Flats Transuranic Waste*" (Wastren, 1995) reports headspace gas analyses for 13 drums containing First Stage Sludge, B774. These are reproduced in Figure 4. These gas analyses show elevated levels of hydrogen well in excess of the 4 % Lower Explosive Limit (LEL) for hydrogen as well as elevated levels of oxygen. Other flammable gases, notably hydrocarbons, were present but in concentrations below their respective LELs.

Based on the historical headspace data, it was concluded that the drum headspace could have contained a combustible mixture of hydrogen and oxygen at the time the drum was being vented.

6.2 Flammability and Ignition of Hydrogen

Mixtures of hydrogen with air, oxygen, or other oxidizers are highly flammable over a wide range of compositions. Flammability and explosion limits for hydrogen in dry air range from 4% LEL to 75% Upper Explosive Level (UEL) [Zalosh, 1995]. The energy required for ignition of hydrogen in air is 0.017 mJ (milliJoule) at 14.7 psi. Thus, low or weak energy, such as that caused by the discharge of static electricity from a human body, may be sufficient to cause ignition of a hydrogen/air mixture [NASA, 1997].

6.3 Potential Ignition Sources

Static Electricity
Static electricity could have been generated during the venting operation as a result of the operation of the vacuum exhaust. The operation of the vacuum exhaust could have produced a static charge on the vacuum hose. Since the drum was situated on a nonconductive surface (i.e., a plastic pallet) and was not bonded or grounded, a static charge produced at approximately the same time the drum was vented could have resulted in ignition of a hydrogen/air mixture being expelled through the vent hole produced by the punch. The flame could have then propagated back into the drum headspace causing a deflagration in the headspace.

Friction or Impact Sparks
Another ignition source is one resulting from friction or impact sparks. The remote drum punch used to vent the drum was powered by a nitrogen system using line pressures in the range of 150 psig. The punch is made of brass and is typically considered a spark resistant material. However, it is capable of producing friction or impact sparks. It was reported that a louder than normal "pop" was heard when the punch penetrated the drum. Thus, it is possible that the remote drum punch process resulted in a friction or impact spark, which served as the ignition source for the drum headspace combustion event.

Self Ignition
Hydrogen, with its low minimum ignition energy has been reported to self-ignite from static electricity [produced] as a result of leaking or venting [Cote, 1990].

6.4 Fire Consequences

"Ignition of a gas-air mixture in an unvented enclosure will usually result in a deflagration (i.e. flame propagation at subsonic speed away from the ignition site) [Zalosh, 2002]. As noted by Zalosh [2002], conservative estimates of burned gas temperature and composition can be obtained by assuming that combustion occurs adiabatically at constant volume. Calculated adiabatic constant-volume pressures resulting from hydrogen deflagrations (in air) can result in maximum pressures in the range of 8 atmospheres. Hydrogen mixtures at or near the lower flammable limit result in overpressures in the range of 3 atmospheres. In this event, the drum had been vented via the punch. Thus, the deflagration occurred in a "vented" condition, but was sufficient to produce overpressures (probably in the range of 3 atmospheres), which resulted in the deformation of the drum lid and bottom, as well as causing venting at the drum lid's weakest points.

The deflagration that occurred in the headspace resulted in flame temperatures at least as high as 980 °K, the adiabatic flame temperature for hydrogen at the Lower Flammability Limit [Beyler, 1988]. High density polyethylene has a thermal decomposition temperature of 506 °K [Beyler and Hirchler, 1995]. Thus, it was concluded that the headspace gas temperature produced by the deflagration would have been sufficient to cause ignition of the polyethylene drum liner (plastic bag).

Once ignited, the resulting polyethylene fire produced soot and other products of combustion. Consistent with vent flows associated with fire dynamics [Emmons, 2002], the heated products of combustion accumulated in the drum headspace and vented through the lid openings. The drum headspace had an approximate depth of 12 inches. When the polyethylene drum liner (plastic bag) ignited, the resulting decomposition process produced smoke, which quickly formed a smoke layer in the drum headspace. The smoke layer propagated quickly down the drum interior, depositing soot along the drum headspace wall and displacing any clean air in the drum headspace available for combustion. Consequently, the fire quickly became self-extinguishing as witnessed by personnel.

7.0 CONCLUSIONS

The event investigation revealed that a combustion event, characterized as a deflagration that generated overpressures, occurred within the headspace of the drum. Although three potential mechanisms for a low energy source of ignition existed (static electricity, friction or impact sparks, and self ignition of hydrogen), the exact source of ignition could not be determined. The flammable gases, believed to be hydrogen and oxygen in the headspace, deflagrated as a result of the low energy initiation source. The resulting fire produced overpressures, which deformed the drum bottom and lid and produced three small holes in the lid.

Interviews conducted by the investigation team revealed that data associated with the type of waste involved in the fire was available prior to the event. This data indicates that all drums of IDC-D001 have the potential to contain a combustible mixture of hydrogen/oxygen, even if the pressures are low and not obvious. Because a 4% hydrogen/air mixture results in a potentially explosive mixture, it is necessary that adequate controls are determined beforehand and put in place to ensure worker safety during the handling and manual venting of these types of waste drums.

Although the potential for ignition of the combustible gases could be reduced through the use of additional pre-determined controls, the investigation team believes, based on the opinions of professional fire protection personnel, that the possibility for complete elimination of the ignition potential cannot be realistically achieved and that it may not be practical to attempt to prevent all fires within a waste drum without extensive engineering controls involving elaborate and complicated systems and structures. Controls as recommended in this report, are intended to improve worker safety during the handling and subsequent venting of these drums and to minimize the potential for a fire. These additional controls, which include revising operating procedures and emergency plans to improve the management of a fire, treating a fire as an expected, although infrequent event. These improvements should place operational control of any recurrence of this type of event within the normal operational procedures and capabilities of the AMWTP and not require the activation of outside emergency response organizations.

8.0 DIRECT, ROOT, & CONTRIBUTING CAUSES

The first step in the investigation of the event was to analyze the available data to determine the causal factors and how each causal factor could occur. Next, the underlying reasons for each causal factor were identified to determine the management system weaknesses that caused or allowed the causal factors to occur. These underlying management system weaknesses are referred to as the contributing and root causes of the causal factors. Then, recommendations were developed to address each contributing cause and the root cause.

8.1 Direct Cause

Equipment used in the remote drum punch venting activity lead to the generation of a low energy initiation source resulting in the ignition of a premixed hydrogen/oxidant mixture, causing a deflagration within the waste drum being vented.

8.2 Root Cause

Inadequate or Defective Design – DOE Cause Code 4B: The process of procuring, evaluating, and configuring the equipment selected for performing manual remote venting of waste drums in Building WMF-636 did not produce a final design that minimized the potential for ignition of combustible gases within a drum.

When equipment was selected for manually venting waste drums, the selection was based on it being commercially available, spark resistant, and having been used in other areas of the DOE complex without incidence. For example, the drum punch tool selected was powered by nitrogen and not electricity and a brass punch was selected because it reduced the potential for sparking. However, other equipment and operational practices were not identified and implemented which could have further reduced the potential for sparking and in this respect, BNFL did not perform the most rigorous analysis. For example, the drum and tool were not electrically grounded. Instead they were placed on a plastic spill pallet that was placed on a plastic sheet; both items effectively isolate the drum and tool electrically from ground. A ventilation system was attached to the drum that rapidly drew air into a plastic hose. Each of these conditions has the potential for generating a static charge that has the potential to dissipate as a low energy initiation source.

Although it was known before this event that the possibility existed that an ignition source could be presented to combustible gases inside a waste drum during venting, the process by which the design of the manual remote drum punch device was determined, considered the punch as the only potential for introducing a source of ignition. Because BNFL did not undertake a formal design review of the procured equipment and its intended use, the specific potential for hydrogen ignition and all potential sources of ignition were not evaluated. Further the hazard potential for a hydrogen deflagration was not identified. Thus, the design process did not identify adequate control measures for reducing this potential hazard.

The design of the remote drum punching device may have met the requirements for a spark resistant tool but requirements for working with hydrogen and combustible gases should demand additional evaluation of ignition sources and determination of adequate controls to minimize the potential for all ignition sources that may be present and to mitigate the consequences of any ignition. Possible design features that were not considered include the use of an enclosure to mitigate the risk of contamination due to fire during the venting process. Additionally, there is industry developed personal protective equipment such as Tyvek suits impregnated with conductive fibers that are available and may have been appropriate to consider.

8.3 Contributing Causes

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for the implementation of changes and for work control at the AMWTP are not explicit regarding the appropriate method and level of rigor to be applied in regards to conducting a hazard assessment of the change.

Various management procedures and instructions direct hazard assessments to be performed based on the scope of work to be completed. These procedures and instructions include INST-COPS-9.18.2, *Permit to Work*, MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, INST-COPS-9.18.4, *Hazard Assessment*, and INST-CD&M-11.1.1, *Facility Modification Screening*.

Examples of the varying methods of hazard assessments that are allowed by these procedures include: 1) INST-COPS-9.18.2, *Permit to Work*, requires a review of the hazards associated with the work by one of several methods. These methods include either a review of INST-COPS-9.18.4, *Hazard Assessment*, or a review of Appendix A of INST-COPS-9.18.2, *Permit to Work*, coupled with the performance of a walkdown of the work area, or by convening a meeting of topic experts; 2) INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, requires only that the preparer of the proposal determine whether or not a hazard assessment is required, and if a hazard assessment is required, that it should be performed in accordance with INST-COPS-9.18.4, *Hazard Assessment*; 3) INST-CD&M-11.1.1, *Facility Modification Screening*, does not require any hazard assessment of the change; rather it requires only answering a series of yes/no questions regarding the effect the change will have. This procedure does; however, require the user to affect the change through other procedures such as the Facility Modification Proposal Preparation procedure or to use "…normal department procedures…"; departmental procedures which do require some level of hazard assessment be performed, 4) INST-COPS-9.18.4, *Hazard Assessment*, clearly states the requirements for performance of a hazard assessment when such assessment is required; this procedure does not contain any optional methods for performing the assessment.

Defective or Inadequate Procedure– DOE Cause Code 2A: The various management procedures that provide direction for work control at the AMWTP can in certain circumstances lead the user to a process for implementation of change, without a sufficient level of review and approval.

MP-CD&M-11.1, *Change Control,* very clearly defines a change at the AMWTP and it also clearly requires that all changes be processed in accordance with INST-CD&M-11.1.1, *Facility Modification Screening*. However, in the case of this event, the personnel involved felt the use of the manual remote drum punching device was not a change, rather they felt it was limited to the use of a new tool and as a result, personnel did not refer to the change control procedure. Rather, they defaulted directly to work control documentation (INST-COPS-9.18.2, *Permit to Work* [PTW]) to implement the use of what they understood to be a new tool.

Based on the wording in the PTW procedure, "*A PTW is required for each task performed at AMWTP, which is not addressed by routine operational instructions or is determined to be minor maintenance*", this procedure can appear to be the appropriate method for processing a change like the use of the remote drum punch system as a tool and would reinforce the decision personnel made that the mechanism wasn't necessarily a change. Based on this, personnel could easily assume that the PTW approach is appropriate. The PTW procedure does not provide guidance on when the more formal Facility Modification Proposal Preparation (FMP) process is required in lieu of the PTW process and because the PTW process procedure is silent regarding the implementation or definition of changes at the AMWTP, it is difficult to determine when the FMP process is appropriate.

When the equipment for the remote venting was procured and "installed", the change did not go through the FMP process outlined in CD&M-11.1.2. Because the FMP process was not used, personnel with the appropriate backgrounds and experience were not involved in the review and approval of the change. Changes that do go through the FMP process are reviewed by a group of senior managers. This review, performed by the Facility Change Group, ensures that a broad review of facility changes is performed. This team is composed of the Operations Manager and representatives from Environmental, Safety, and Health; Radiological Safety; Quality; Operations; Engineering; and Maintenance organizations. This additional review would also have been likely to identify the need for additional controls regarding this event.

Inclusion in INST-COPS-9.18.2, *Permit to Work,* of the definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* in addition to including other checks the user would be required to conduct to verify the work is not a change would provide an additional level of defense in depth to ensure changes are processed in accordance with the FMP process.

9.0 OBSERVATIONS

Four additional items were identified during the investigation that did not directly contribute to this event. However, they are potential contributors to other possible loss scenarios.

Observation #1 – The occurrence of an explosion/deflagration is identified in the safety basis documentation as an anticipated event for the facility; however, operational procedures regarded the event as an emergency, which required management of the event with the assistance of outside agencies and emergency response organizations.

The *AMWTP Documented Safety Analysis for Retrieval Operations* (DSA) discusses in several sections this event. The DSA, Section 3.3.2.3 describes the explosion/deflagration of volatile liquids or gases during handling in the characterization building as being representative of similar accidents that could occur in retrieval or during transport. This event has been analyzed with the most likely explosion that could occur during venting would be a small hydrogen flash with no consequences. The small hydrogen flash is an anticipated operational event that would neither challenge the enclosures nor result in an accidental release of either radioactive or hazardous material.

Although this event is analyzed as being an anticipated operational event, the AMWTP operating procedures and emergency plans do not adequately address the likeliness of this event such that the event can be adequately controlled through the use of operational procedures and instructions. As currently written, AMWTP procedures require unnecessary activation and response by outside agencies when the event occurred.

Observation #2 – Procedures that direct drum venting using the remote drum punch system can be enhanced to more specifically provide instruction while drums are handled during segregation and subsequent venting.

The current procedures (Operating Instructions INST-OI-09, Rev. 15, *Retrieval Enclosure Waste Container Extraction,* and INST-OI-11, Rev. 15, *Waste Container Handling)* include steps to inspect the condition of waste drums shortly after they are removed from the waste stack. If there is any visible bulging of the drum, the procedure requires the operators to suspend all waste handling operations in the vicinity of the container, warn others in the area, place equipment in a safe and stable condition, evacuate personnel from the immediate area and secure access, notify appropriate supervision, attempt to determine the contents of the container by means of the Waste Tracking System (WTS) barcode number (if available) and any other pertinent information (from labels, etc.) that can be used to plan remedial actions. The operators are then directed by the operating instruction to develop and execute a course of action under the work control process or to remotely vent the drum with the remote drum punch system. The process relies on visual indications to determine if the drum requires venting in WMF-636.

BNFL established a correlation between the internal pressure in the drum and the external indications of drum pressure based on historical data from the Department of Energy (Safety Notice Issue No. 93-01). This correlation allows personnel to estimate the internal drum pressure prior to handling and manually venting the drum. However, the hazards associated with the potential presence of hydrogen and oxygen in the headspaces of the drums have not been addressed in this procedure therefore there is no additional guidance in the procedure for properly and safely handling and segregating the suspect drums.

Observation #3 – Approximately 72 hours after the event, a headspace gas sample indicated higher than atmospheric oxygen concentration. The team was not able to determine a mechanism to explain this observation.

Approximately 72 hours after the event, a sample was taken of the headspace gas for drum IDRF07411511. Analysis of the sample indicated higher than atmospheric oxygen content (about 24%). Assuming the fire was self-extinguished because of oxygen depletion within the headspace of the drum, the oxygen concentration within the headspace would have been below atmospheric concentration (about 20%) immediately following the event. Therefore, in about 3 days, the oxygen concentration rose at least a few percent.

The team was not able to determine a mechanism to explain this observation. This may have health, safety, or environmental consequences for the processing steps that take place after the drums are vented.

Observation #4 – Even though fire was specifically identified as a potential hazard, a qualified Fire Protection subject matter expert was not consulted during the hazard assessments. This additional input could have resulted in identifying controls that would have minimized the potential for ignition.

Several hazard assessments were performed regarding the use of the remote drum punch device. The first assessment was completed in accordance with procedure INST-COPS-9.18.2, *Permit to Work*, prior to the initial use of the remote drum punch. A second assessment was completed in accordance with INST-COPS-9.18.4, *Hazard Assessment,* after the remote drum punch had been placed into service and used successfully a number of times. While the fire hazard and worker safety was specifically addressed during both of these reviews, the procedures being used to conduct the hazard assessments failed to cause the identification of additional controls that could have minimized the potential for ignition of the drum gases. INST-COPS-9.18.4, *Hazard Assessment,* requires that the overall makeup of each assessment team will be on a case-by-case basis as determined by the targeted assessment and that the team makeup must include Industrial Safety or Industrial Hygiene professionals and Operations, Radiological and Maintenance technicians who have involvement with the building, facility, and/or process being evaluated in addition to the discipline specific topic experts. There is no guidance in the procedures that would prompt the identification of "discipline specific topic experts".

Identification of other potential ignition sources by a qualified Fire Protection subject matter expert during the hazard assessments could have resulted in additional controls that would have minimized ignition sources and mitigated the deflagration/explosion hazard. Although it was recognized by the personnel involved in the hazard assessments that a "non-sparking" punch was required as a control, the procedures did not direct personnel to obtain an evaluation or screen by a qualified Fire Protection subject matter expert to determine appropriate controls to be applied to the task.

10.0 RECOMMENDATIONS

Recommendations include revisions to appropriate operating procedures, emergency plans, and the underlying safety basis documentation associated with drum fires during controlled venting operations. Operating procedures should be revised to include the appropriate engineering controls to reduce the potential for a drum fire/deflagration and to mitigate the consequences if a fire/deflagration does occur during remote drum venting operations. Revisions to emergency plans and underlying safety basis documentation should be considered, consistent with the level of work controls in place for the venting process (equipment and procedural controls).

Because outside emergency response did not contribute significantly to this event (i.e., there was no fire to extinguish, there was no release to the environment, and there were no injuries) the team believes that once the additional controls outlined in these recommendations are implemented, no additional outside emergency response should be required for a properly mitigated fire/deflagration in a single drum during the controlled venting process.

10.1 Recommendations Related to Direct, Contributing, and Root Causes

Design Issues

1. Redesign and modify the remote drum punch system. Based on this redesign effort, include additional engineered controls for ignition control, fire/deflagration mitigation, and worker safety. Controls such as grounding of the waste drum and associated equipment, enclosure/containment for an energetic release of pressure, and lid containment during the venting process should be considered. It is highly recommended that the redesign of the drum punching system include a review of the reference materials cited in this report in identifying the hazards and developing appropriate controls. This recommendation addresses the root cause of the event; Inadequate or Defective Design.
2. Review and approve the modified manual remote venting process using INST-CD&M-11.1.2, *Facility Modification Proposal Preparation,* (FMP) process. This recommendation addresses the root cause of the event; Inadequate or Defective Design.

Hazard Assessment

3. MP-CD&M-11.1, *Change Control*, INST-CD&M-11.1.2, *Facility Modification Proposal Preparation*, and INST-CD&M-11.1.1, *Facility Modification Screening, require the performance of a hazard assessment; however, they should be revised to specifically require* conducting the assessment in accordance with INST-COPS-9.18.4, *Hazard Assessment.* This recommendation addresses the contributing cause of the event; Defective or Inadequate Procedure.

Procedures and Work Process

4. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include appropriate controls for worker safety during handling and setup of drums before the actual drum venting commences such as the use of a lid containment device, segregated storage, physical barriers, etc. This recommendation addresses observation #2.

5. Revise INST-OI-09, *Retrieval Enclosure Waste Container Extraction*, and INST-OI-11, *Waste Container Handling*, to include the necessary engineering controls recommended in this report to reduce the potential for, and mitigate the effects of a single drum fire/deflagration or explosion during the operations bounded by these operating instructions. This recommendation addresses observation #1.

6. Revise INST-COPS-9.18.2, *Permit to Work,* to provide a definition of a facility change, as stated in MP-CD&M-11.1, *Change Control,* and to include additional checks the user would be required to conduct to verify the work is not a change that must be processed through the FMP process. This recommendation addresses contributing cause; Defective or Inadequate Procedure.

7. Revise the requirements of the hazard assessment process, INST-COPS-9.18.4, *Hazard Assessment,* to ensure that personnel with a background in fire protection engineering are included, as appropriate, on the assessment team when the potential for a fire hazard exists. This recommendation addresses observation #4.

Event Response

8. Revise the facility emergency plans, operating procedures, and underlying safety basis documentation, such that the required actions for control of abnormal and infrequent situations of future events similar in magnitude to this event are bounded by the revised implementing procedures and do not require unnecessary activation of emergency response personnel and support organizations. This recommendation addresses observation #1.

11.0 LESSONS LEARNED

1. When planning work activities associated with drums that are known to experience gas generation, the probability of a fire event should be considered. Based on safety basis documentation and information that is readily available within the DOE complex regarding the generation of combustible gases within waste drums, the flammability of those gases should be obtained and used to determine adequate controls to minimize fire/deflagration potential based on the predetermined probability of occurrence.

2. Facility operating procedures and emergency plans should be written consistent with the safety basis documentation regarding the probability of occurrence and significance of consequences to prevent an inappropriate level of activation of emergency response organizations. The probability of and consequences from an event should be considered when developing facility operating procedures to ensure the appropriate and required actions are included for facility personnel to perform; when such actions are clearly within the capabilities of the facility.

3. The process of developing and implementing work controls for new work activities benefits from performing a "what-if" analysis to evaluate the potential desired (and undesired) outcomes of a work task. This what-if evaluation of a new work activity results in the ability to adequately plan mitigation in the actual case of an event such as a fire/deflagration or equipment failure. Additionally, the process of evaluating new work activities benefits from considering the worst-case scenario of a given task. Defining the worst conditions of an activity allows for proper mitigation (in the form of engineering and administrative controls) necessary to reduce the severity of consequences in the actual case of an event such as a fire or equipment failure.

12.0 REFERENCES

1. Beyler and Hirchler, 1995. *Thermal Decomposition of Polymers. Society of Fire Protection Engineers, Fire Protection Handbook.* 2nd Edition, 1995. National Fire Protection Association, Quincy Mass.

2. Beyler, 1988. "Flammability Limits of Premixed and Diffusion Flames". SFPE Handbook of Fire Protection Engineering. 1988. National Fire Protection Association, Quincy, Mass.

3. Cote, 1990. *Industrial Fire Hazards Handbook*, Third Edition, Chapter 43. National Fire Protection Association, Quincy Mass.

4. DOE, 1993, Safety Notice 93-01, *Pressurized Drums, What Every Handler Should Know.*

5. DOE, 2003, *[AMWTP] Tri-Party Memorandum of Agreement for BNFL Inc, Department of Energy and Bechtel BWXT Idaho LLC,* DOE/ID-10520 Rev 3.

6. Emmons, 2002. "Vent Flows". SFPE Handbook of Fire Protection Engineering, 2002. National Fire Protection Association, Quincy, Mass.

7. NASA, 1997. *Safety Standard for Hydrogen and Hydrogen Systems, Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage and Transportation.* Effective date 1997. Office of Safety and Mission Assurance, Washington, DC 20546.

8. Wastren, 1995, *Idaho National Engineering Laboratory Code Assessment of the Rocky Flats Transuranic Waste*, INEL [INEEL] Report 95-0281.

9. Zalosh, 1995. *Explosion Protection*, Society of Fire Protection Engineers, Fire Protection Handbook. 2nd Edition, 1995. National Fire Protection Association, Quincy Mass.

13.0 APPENDICES

Appendix A, Figures

Appendix B, Photographs

APPENDIX A
FIGURES

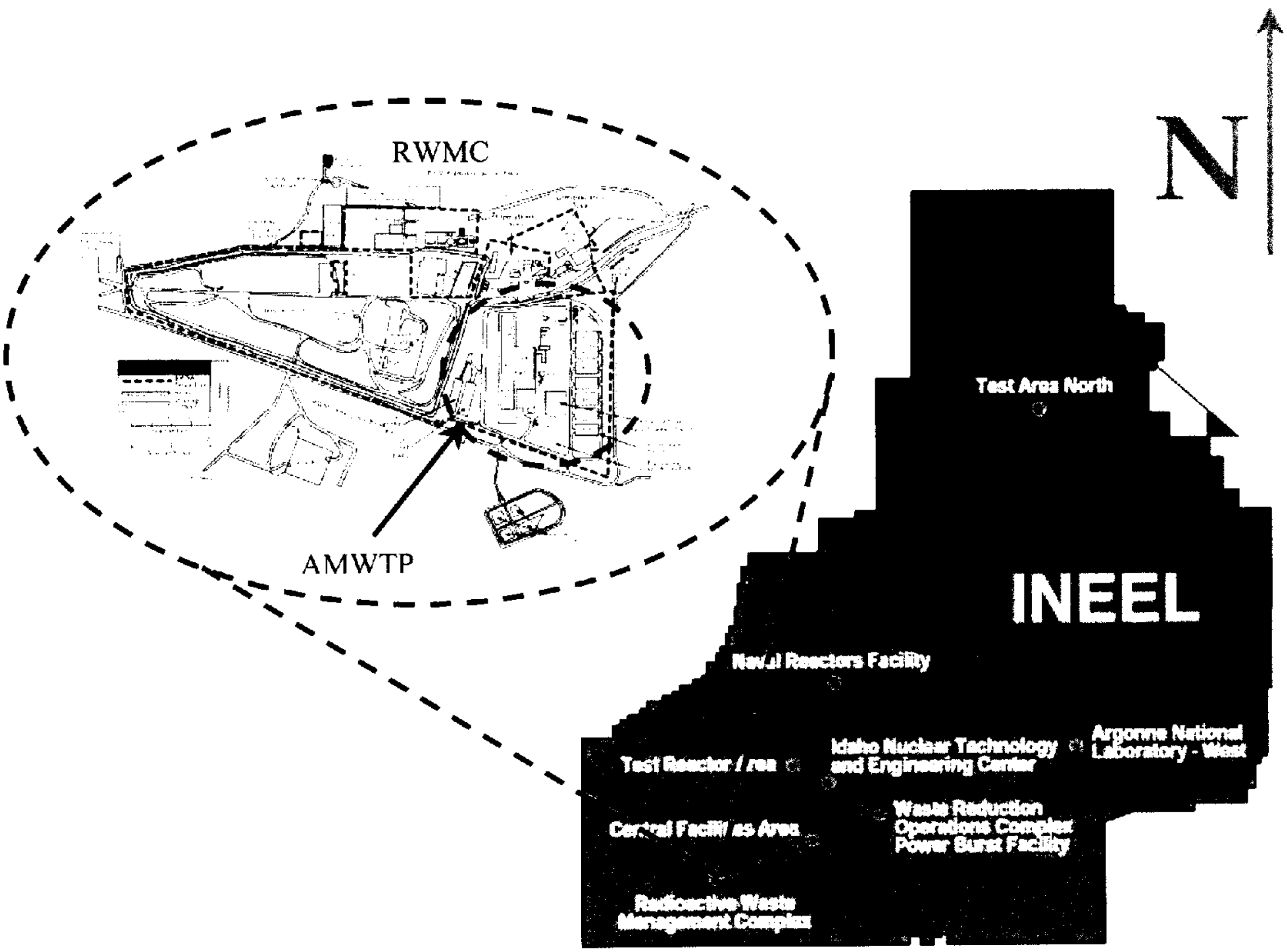


Figure 1: Map showing the location of the RWMC and AMWTP within the INEEL.

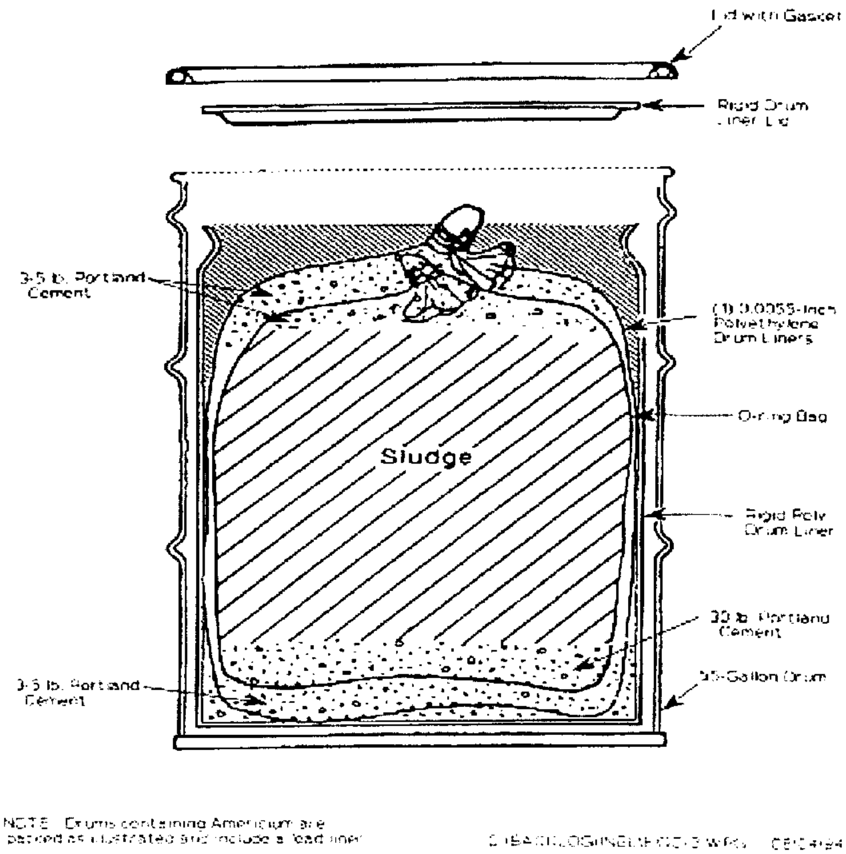


Figure 2: Typical packaging for drums with IDC Code D001, like the one involved in the event (Wastren, 1995).

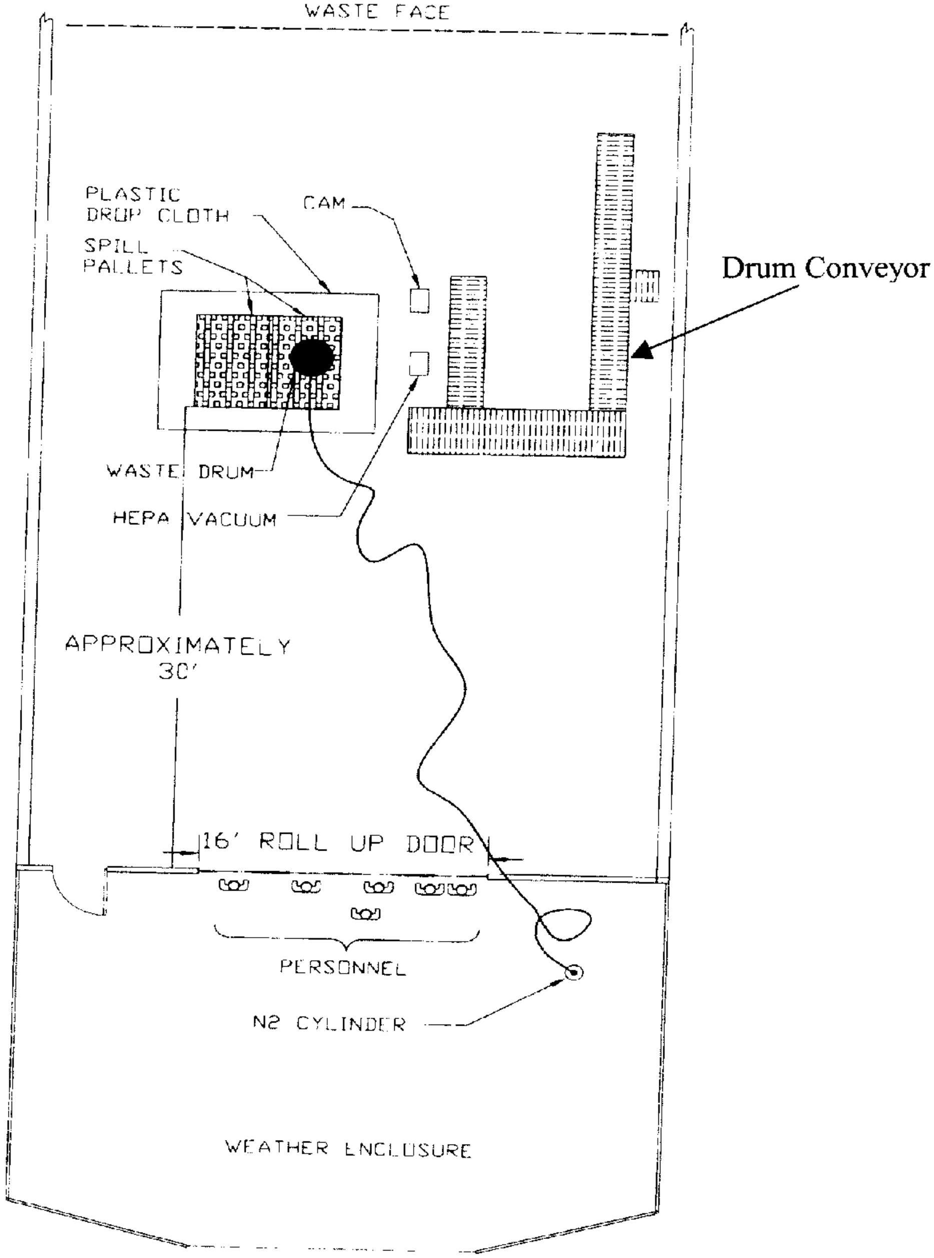


Figure 3: Plan view representing the configuration of the Remote Drum Punch equipment and personnel locations relative to the waste drum in WMF-636.

Table 3.1.1-11. Gas Sampling Results—Compositional Analysis (vol%).

Container ID.	Storage time (days)	Analytes H_2	O_2	N_2	Ar	CO_2	CO	NO_x	Hydrocarbons (saturated)[1]	1,1,1-trichloro-ethane	Other Hydrocarbons[2]
7412-03121	144	0.03	21.1	77.5	0.94	0.02	—	—	0.07	0.29	0.04[a]
7412-03125	144	0.24	18.2	80.2	0.96	0.01	—	—	0.06	0.30	0.04[a]
7412-03127	144	0.18	18.1	79.9	0.95	0.02	—	—	0.13	0.58	0.12[a]
7412-03128	144	0.11	20.1	77.5	0.94	0.02	—	—	0.11	0.94	0.22[a]
											0.01[b]
7412-00483	1,089	1.2	21.1	76.4	0.90	0.09	—	—	0.35	—	—
7412-00636	975	5.30	15.6	77.4	0.96	0.11	—	—	0.24	0.38	—
7412-00766	904	2.02	21.0	75.5	0.95	0.11	—	—	0.16	0.24	—
7412-00797	902	0.78	3.87	94.0	1.2	—	—	—	0.11	—	—
741-12404	4,326	5.19	65.9	27.7	0.32	0.09	—	0.66	—	—	—
741-12794	4,205	4.12	46.8	48.0	0.58	0.14	—	0.27	—	0.05	0.04[c]
741-12858	4,213	11.7	35.7	51.3	0.61	0.14	—	0.46	—	0.04	0.01[c]
741-12387	4,304	1.85	30.9	66.2	0.79	0.09	—	0.15	—	0.03	0.01[c]
741-12795	4,203	11.0	73.4	14.5	0.17	0.13	—	0.63	—	0.94	0.02[a]
											0.01[b]

1. Saturated hydrocarbons—methane through propane.

2. Other hydrocarbons—as specified.

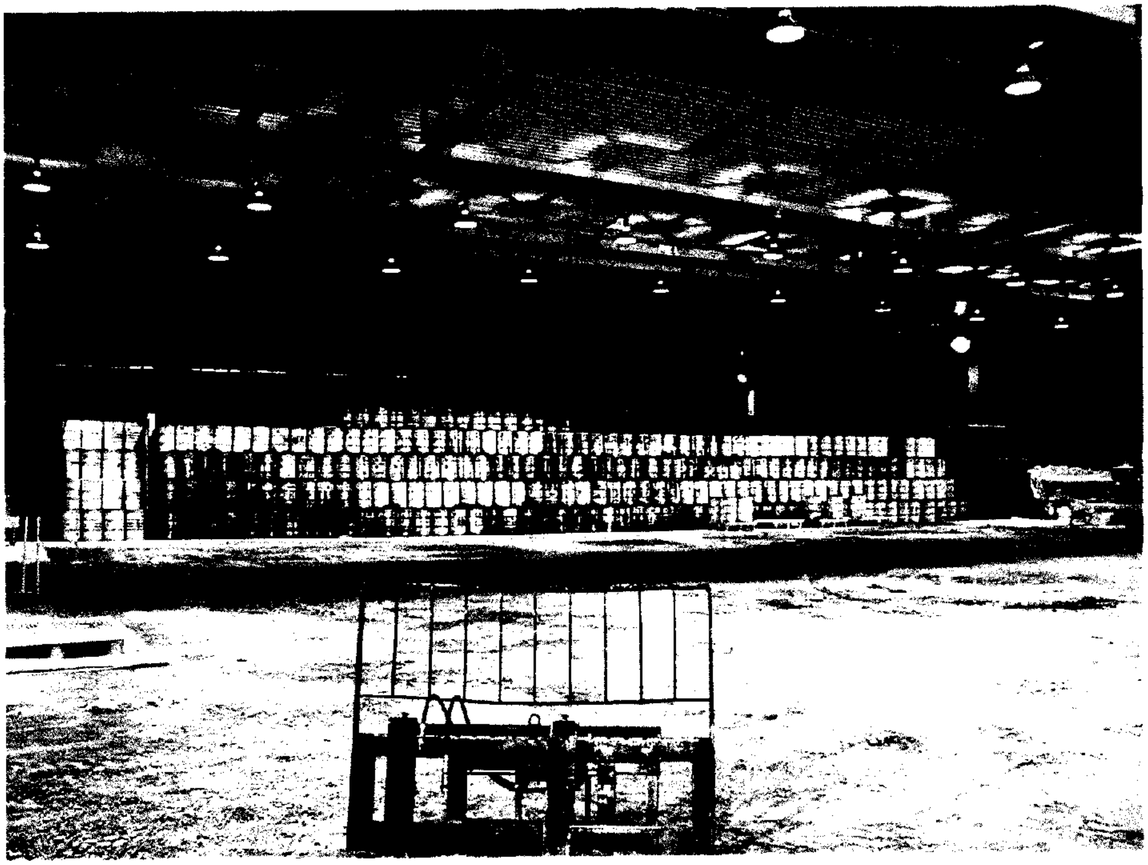
a. Dichloromethane

b. Carbon tetrachloride

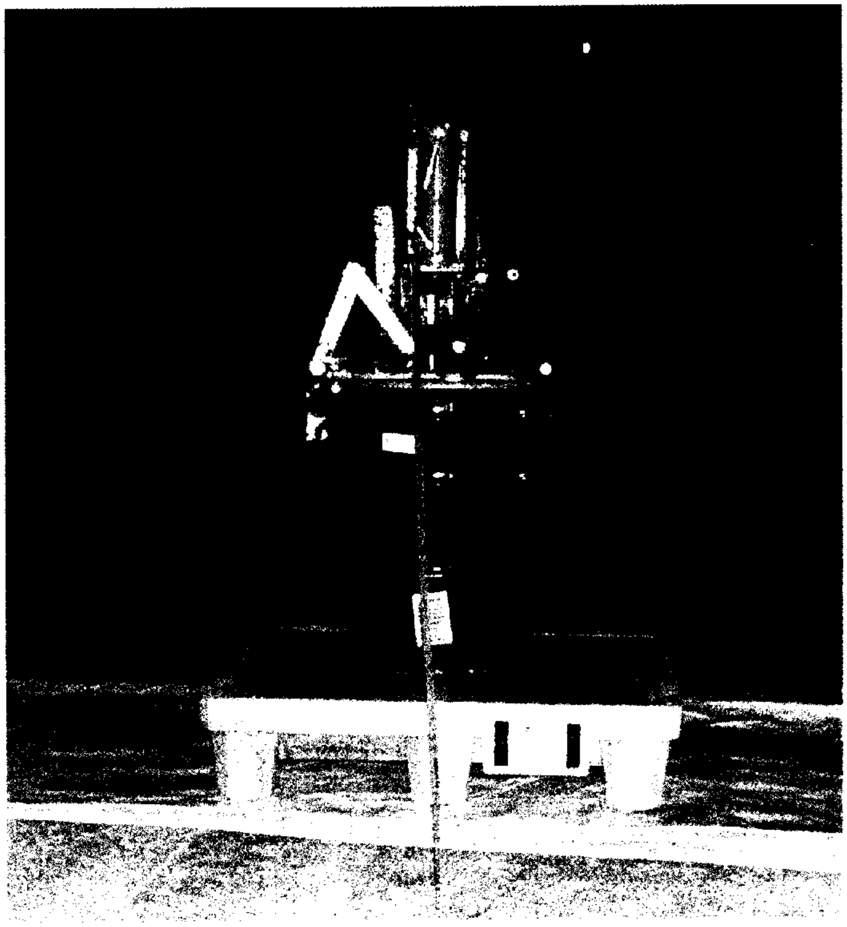
c. Trichloroethylene

Figure 4: Table showing the gas sampling results from 13 drums from the same IDC as the drum involved in the event (Wastren, 1995).

APPENDIX B
PHOTOGRAPHS

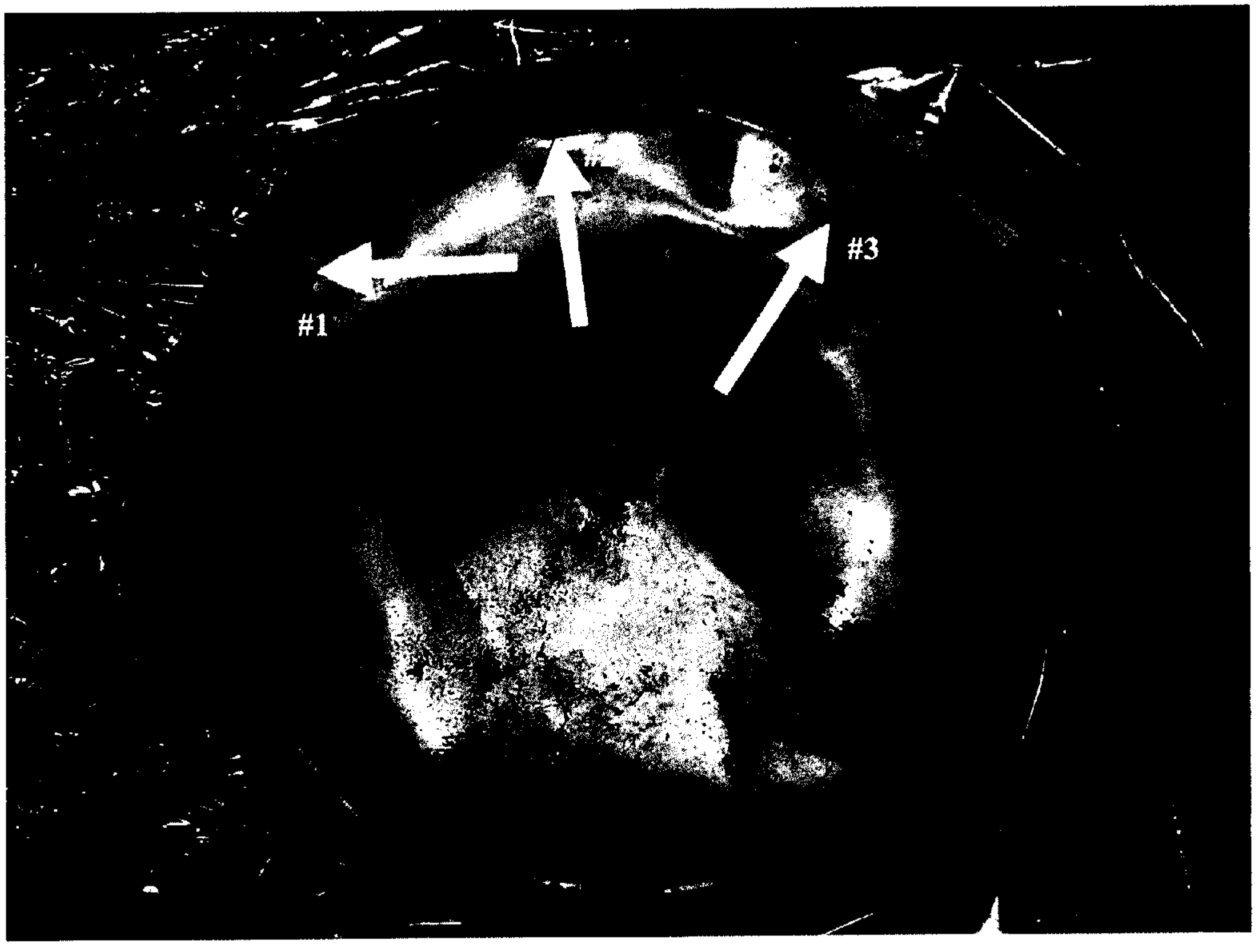


Photograph 1: Interior of the Transuranic Storage Area – Retrieval Area; the drum being vented during this event was off to the right of this picture.



Photograph 2: Typical setup of the remote drum punch located on top of a typical 55-gallon waste drum showing the typical arrangement of the waste drum, plastic spill pallet, plastic sheeting and the remote drum punch tool.

Photograph 3: Drum lid post-event, prior to removal, showing bulging.

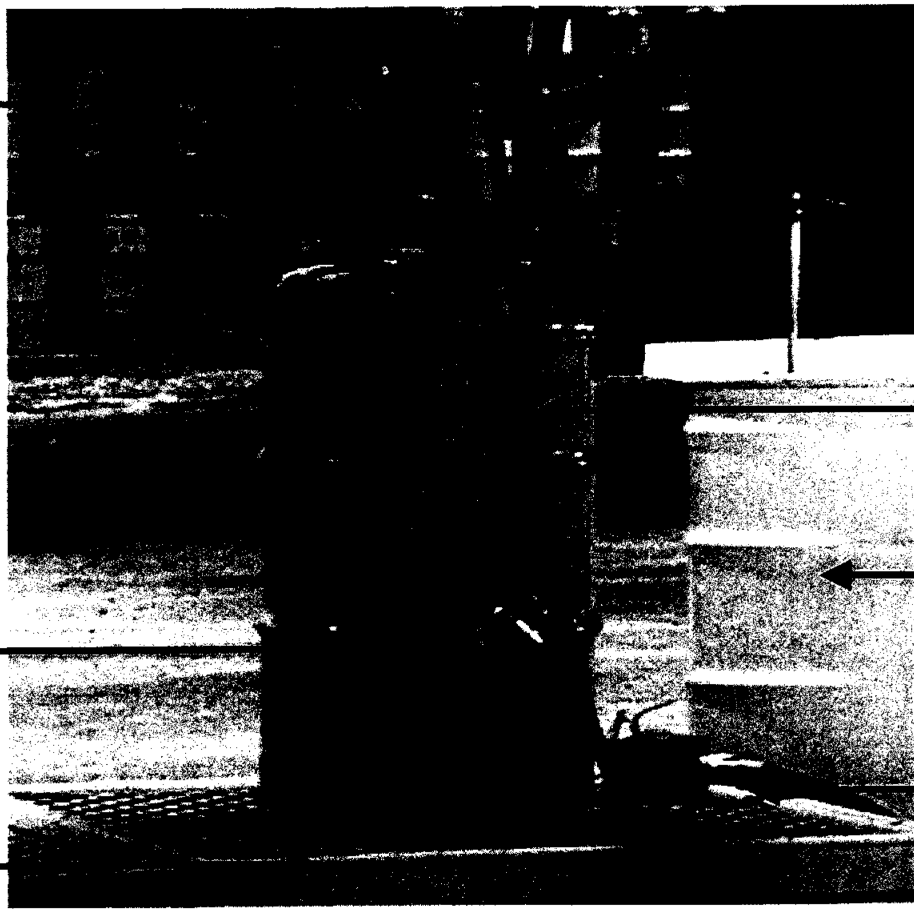


Photograph 4: Inside of the drum top showing the locations of the three holes that were formed during the event – Close-up photos are shown below.

Waste Stack

Combination Vent Filter Assembly

Spill Pallet

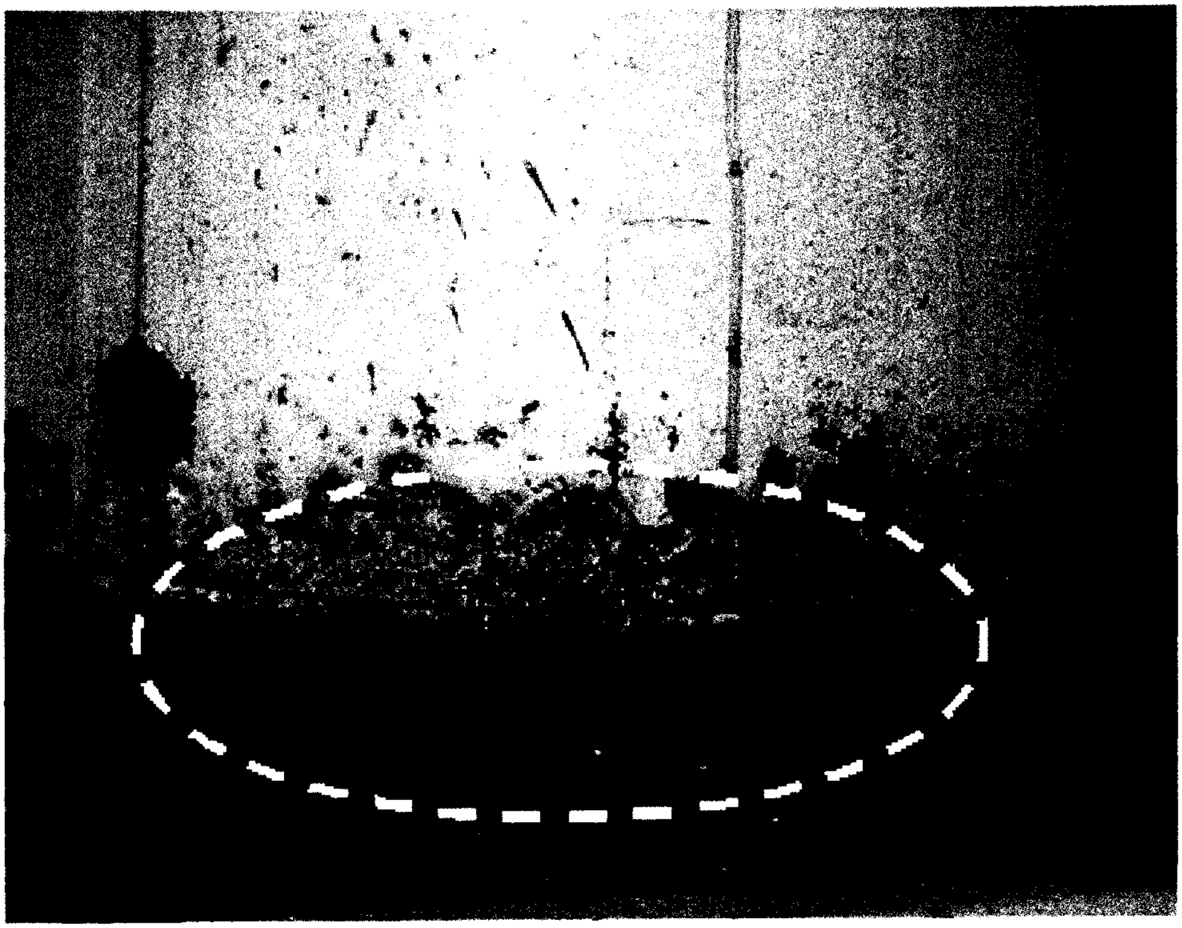


N2 Actuation Hose

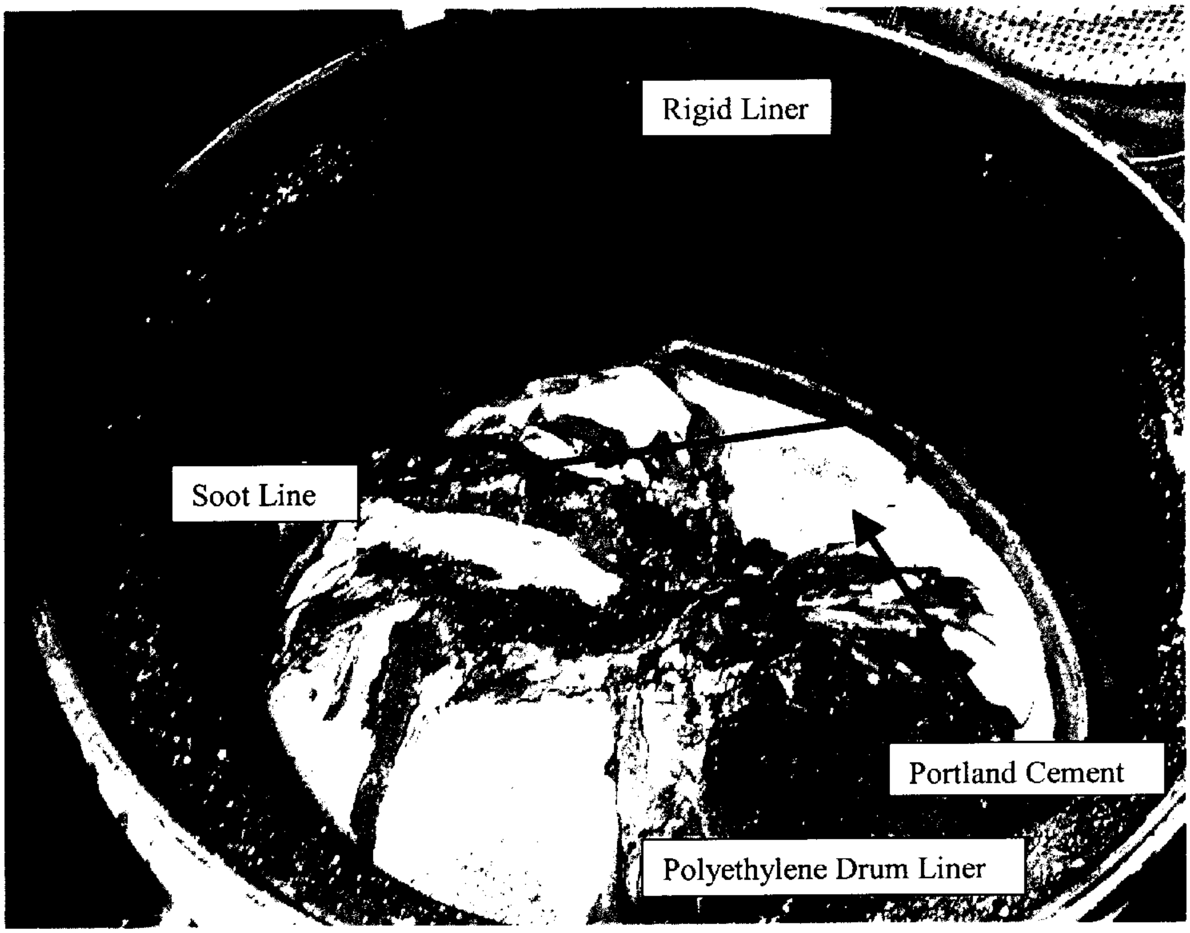
Pre- Staged Overpack drum

Down-Draft Vacuum Hose

Photograph 5: Post event photo obtained during the event showing the affected drum and the Remote Drum Punch tool and other equipment associated with the drum venting. Note the left side of the Remote Drum Punch tool has been forced upward by the event.



Photograph 6: Lower end of the affected waste drum after the event. Note the lifting and tilting of the drum caused by the bottom of the drum bulging and protruding downward.



Photograph 7: Interior of the drum following the fire, showing the soot line about 12 inches below the rim of the drum.