Type B Accident Investigation Board Report
Employee Puncture Wound at the F-TRU Waste Remediation Facility
June 14, 2010

September 2010
U.S. Department of Energy
Savannah River Site

Disclaimer

This report is an independent product of an Accident Investigation Board appointed by Jack R. Craig, Acting Manager, Department of Energy Savannah River Operations Office.

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

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

This report neither determines nor implies liability.

Acceptance Statement and Release Authorization

On July 28, 2010, I established a Type B Accident Investigation Board to investigate the employee puncture wound at the Savannah River Site F-TRU Waste Facility. The Board's responsibilities have been completed with respect to this investigation. The analyses and the identification of contributing causes, the root cause, and judgments of need resulting from the investigation were performed in accordance with DOE Order 225.1A, *Accident Investigations*.

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

Jack R. Craig
Acting Manager
Savannah River Operations Office

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EXECUTIVE SUMMARY

This report documents the results of the Type B Accident Investigation Board investigation of the June 14, 2010, employee puncture wound at the Department of Energy (DOE) Savannah River Site (SRS) F-TRU Waste Facility located in the F Canyon facility.

Accident Summary

While performing transuranic (TRU) waste remediation work inside a special process enclosure (Enclosure), a Technician received a puncture wound near the base of the index finger on his right hand. The Technician was placing a hole indicating device (a wire survey flag) into a quart-sized waste can that had previously been punctured. The can had been punctured to eliminate a potential concern with pressurization and to ensure no free liquids were present in the interior of the can. The hole indicating device was used to enable radiography to confirm at a later date that the can had been punctured and was not pressurized. The technician bent the indicating device into a "U" shape and the uncovered end of the device punctured his personal protective equipment, resulting in internal contamination with transuranic elements. At the time of the accident, other workers were present in the area conducting similar work and performing radiological surveys. Personal protective equipment was in use for the work being performed.

Facility Description

DOE's complex-wide waste management strategy includes shipping TRU waste from generator sites to the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. TRU waste generated at SRS and waste generated at other sites and shipped to SRS for interim storage is repackaged and remediated, as needed, to ensure that the waste containers meet the requirements to be accepted for disposition at WIPP. TRU waste drums identified by radiography to potentially contain containerized liquids, pressurized cans, or other prohibited items are processed in F Canyon to remove liquids and other items prohibited by the WIPP Waste Acceptance Criteria. The Enclosure was installed in the F Canyon Warm Crane Maintenance Area to support remediation of TRU drums.

The Enclosure consists of four sections: a loading area, the processing area, the waste removal area, and a wing cabinet. The loading area is where the waste drums enter the Enclosure. The processing area is where waste is removed from a TRU drum, inner cans are punctured to relieve potential pressurization, prohibited items are segregated, and liquids are immobilized. The wing cabinet is used to store tools used in the remediation process. Waste is removed from the Enclosure in the waste removal area using standard bag port techniques, and placed into drums(s) for eventual disposition at WIPP.

The Enclosure processing area is supported by a stainless steel frame. The sides and top are constructed of a combination of flexible and rigid fire-retardant materials. Ventilation is provided by blowers that provide airflow through the Enclosure, with additional blowers available for backup. Proper airflow is monitored by measuring the differential pressure across the Enclosure. The only electrical equipment in the Enclosure is the drum lifter. Battery-operated tools are used in the process area of the Enclosure and low-voltage electrical equipment (including a video camera) is present in the process area.

Summary Facts and Analysis

While performing TRU waste remediation work inside a special process enclosure, a Technician received a puncture wound near the base of the index finger on his right hand. The Technician was placing a hole indicating device (a wire survey flag) into a quart-sized waste can that had previously been punctured. The technician bent the indicating device into a "U" shape and the uncovered end of the device punctured his personal protective equipment, resulting in internal contamination with transuranic elements.

Savannah River Nuclear Services, LLC (SRNS) provided an initial range (low and high) projection of the worker's final dose on August 9, 2010. The range was estimated to be between 5 and 50 rem committed effective dose to the whole body and between 166 and 1657 rem committed equivalent dose to the bone surface from this intake. Based on the dose projections provided, it is indeterminate whether this event met the threshold for a Type A Investigation.

The root cause of the accident was a less than adequate graded approach used for high hazard TRU waste remediation work; this did not coincide with the discipline warranted for high hazard work.

The Board also identified significant contributing causes to the accident, as follows:

- Management did not follow established protocols to ensure that Subject Matter Experts were involved in the identification and analysis of hazards.
- Management did not ensure that a formal hazard analysis was conducted for use of the hole indicating devices.
- The procedure did not identify a method for hole indicating device installation.
- Formal training was not provided on survey flag installation. Management demonstrated survey flag installation for one-gallon cans but did not provide additional training on one-quart cans.
- Technicians did not follow the demonstrated method of installing survey flags and did not notify management of their concerns that the survey flag would fall out of the one-quart cans.
- Management was unaware that alternate, unapproved methods of installing survey flags were being used.
- Technicians did not understand the safety significance of modifying prescribed equipment and not following survey flag installation as demonstrated.
- Management did not reinforce to workers the importance of disciplined operations, including use of time-outs and the need to discuss issues during pre- and post-job briefings.
- Known accident precursors were not adequately dispositioned and continued to exist in the workplace.

Table ES-1 lists the Board's Conclusions and Judgments of Need identified during the course of this investigation. Appendix E lists additional opportunities for improvement the Board identified during the investigation.

Table ES-1: Conclusions and Judgments of Need

Conclusions	Judgments of Need
The overall emergency response and the treatment actions provided during this accident were adequate. (Section 2.3)	N/A
Initial radiological protection survey techniques were not in compliance with SRNS Manual 5Q, *Radiological Control*, and the patient was not informed of proper contamination control techniques associated with collection of bioassay voids. (Section 2.3)	JON-1: SRNS needs to reinforce compliance with established procedures for personnel survey techniques following an accident. JON-2: SRNS needs to revise and implement protocols for patient instructions associated with chelation.
SRNS's reluctance to share the dose projections from the initial intake impacted DOE's ability to categorize this event in a timely manner based on dose. (Section 2.4)	JON-3: DOE-SR needs to provide clear direction to its contractors to ensure that initial dose estimates are provided as soon as possible following notification of a personnel intake.

Conclusions	Judgments of Need
DOE-SR failed to ensure that the contractor maintained adequate control of the accident scene prior to arrival of the Accident Investigation Board as required by procedure. (Section 2.5)	JON-4: DOE-SR needs to ensure that accident scenes are preserved in accordance with established procedures and formally turned over to the Accident Investigation Board upon arrival.
SRNS did not preserve and control the accident scene prior to turnover to the Board in accordance with DOE O 225.1A and SRNS procedures. (Section 2.5)	JON-5: SRNS needs to ensure that accident scenes are preserved in accordance with established procedures and formally turned over to the Accident Investigation Board upon arrival.
The commitment to comply with Integrated Safety Management System and regulatory requirements was adequately captured in contract documents and site-level procedures. (Section 3.1)	N/A
The scope of work for the remediation and repackaging work was not fully defined, and the methods used to ensure the development of procedures compliant with SRNS Manual 2S, *Conduct of Operations*, had not matured. (Section 3.2)	JON-6: SRNS needs to improve the rigor of the methods used to ensure quality procedures.
Hazards associated with TRU waste remediation activities were not adequately identified and analyzed. (Section 3.3) Management failed to ensure the development and implementation of adequate controls to protect workers during the TRU waste remediation process. (Section 3.4)	JON-7: SRNS needs to ensure that hazards and controls are identified and properly incorporated into technical work documents.
	(continued)

Conclusions	Judgments of Need
The Technician was not wearing all of the prescribed personal protective equipment required by the Radiological Work Permit. (Section 2.6) Management and other contractor oversight groups missed the opportunity to improve working conditions and ensure compliance with expectations by not entering the workspace and observing work first hand. (Section 3.5) Management did not establish appropriate expectations for disciplined conduct of work, did not institutionalize meaningful corrective actions for significant issues, and did not effectively oversee the performance of work. (Section 3.5) The corrective actions taken to address previously identified issues involving hazards analysis were not effective in preventing a recurrence of the identified deficiencies. (Section 3.6) While the conduct of contractor readiness reviews was adequate, the disposition of issues identified during the reviews was not comprehensive, formal, or long-lasting. (Section 3.6) Although an active contractor assessment program existed at the F-TRU waste remediation project, an opportunity was missed to identify hazards associated with the use of a survey flag during remediation activities by not assessing work in the actual work location. (Section 3.6) The process for evaluating and implementing Occurrence Reporting and Processing System corrective actions and lessons learned was not fully effective. (Section 3.6)	JON-8: SRNS needs to ensure that management and supervision enforce the expectation that work is conducted in accordance with procedures, increase the scrutiny of corrective action reviews to ensure adequacy of the corrective actions to prevent recurrence of previously identified deficiencies, and maintain an effective presence at the work site.
During performance of Procedure 221-F-55006 at the mock-up facility, a less than adequate display of disciplined operations in accordance with SRNS Manual 2S, *Conduct of Operations*, was demonstrated. (Section 3.5)	JON-9: SRNS needs to ensure that First Line Managers display leadership and command-and-control at the work site.
A shortened (cut) survey flag allowed the Technician's glove to be punctured more easily than a new survey flag. (Section 2.6) An opportunity was missed to effectively use a "Time Out" to address issues related to survey flag installation and receive formal disposition (including a proper hazards review) prior to developing new methods of installation and shortening the survey flags. (Section 3.5)	JON-10: SRNS needs to reinforce the use of "Time Out" to resolve issues prior to altering work steps or equipment in the field.

Conclusions	Judgments of Need
Management did not consider installation of the survey flags a critical step or a hazardous activity, and the activity was therefore not necessarily observed or recorded on video. (Section 3.5)	JON-11 SRNS needs to ensure that critical (irreversible) steps in procedures are identified so that proper precautions can be taken prior to performance.
Pre-and post-job reviews were not fully effective. (Section 3.5)	JON-12: SRNS needs to improve the effectiveness of pre- and post-job reviews.
DOE-SR Assistant Manager for Nuclear Materials Stabilization Project Facility Representatives and management were actively engaged in oversight of TRU waste remediation activities in F Canyon and provided the contractor appropriate and meaningful feedback through Monthly Assessment Reports, monthly contractor feedback meetings, and a DOE letter of concern issued prior to the accident. (Section 3.6)	N/A
The Board concluded that not all corrective actions related to TRU repackaging and handling sharps were properly incorporated into the F Canyon TRU work. While several engineering controls were in place for the TRU remediation and repackaging process, many steps in the process were still done by hand. (Section 3.6)	JON-13: SRNS needs to minimize human contact in TRU waste remediation and repackaging work by using engineering controls, and choose a better selection of PPE to protect personnel from potential hazards when engineering controls are determined not to be practical.
Training and qualifications for personnel associated with the F Area TRU waste remediation work did not ensure that personnel had the knowledge, skills and abilities commensurate with their responsibilities. Furthermore, the training was not sufficient to provide workers with an adequate understanding of the hazards they would encounter during the performance of the work. (Section 3.7)	JON-14: SRNS should evaluate the skill mix for the TRU waste remediation work to ensure an appropriate level of experience is used for work involving TRU waste. JON-15: SRNS should ensure that the training program established for personnel involved with TRU waste remediation and repackaging activities complies with Manual 4B. This training should include more detail on hazards and consequences, prior to the restart of remediation and repackaging work.
Facility management's lack of engagement of the Training organization in the review of procedure revisions resulted in missed opportunities for the development of formal training for new hazards and controls associated with TRU waste remediation work. (Section 3.7)	JON-16: SRNS needs to ensure that facility managers involved in TRU remediation work increase the involvement of the Training organization in the review of procedure revisions.

ACRONYMS AND ABBREVIATIONS

AHA	Assisted Hazards Analysis
Board	Accident Investigation Board
ARA	Airborne Radioactivity Area
ARRA	American Recovery and Reinvestment Act
CED	Committed Effective Dose
dpm	disintegrations per minute
DOE	U.S. Department of Energy
DTPA	diethylenetriaminepentaacetate
DSA	Documented Safety Analysis
HCA	High Contamination Area
ISM(S)	Integrated Safety Management (System)
OFI	Opportunity for Improvement
ORPS	Occurrence Reporting and Processing System
PEC	Plutonium Equivalent Curie
PPE	Personal Protective Equipment
Pu	Plutonium
RA	Radiation Area
REAC/TS	Radiation Emergency Assistance Center / Training Site
rem	roentgen equivalent man
RPI	Radiological Protection Inspector
RTR	real-time radiography
RWP	Radiological Work Permit
SIMTAS	Site Integrated Management Total Assessment System
S/RID	Standards / Requirements Identification Document
SR	Savannah River Operations Office
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions, LLC
SRS	Savannah River Site
SRSOC	Savannah River Site Operations Center
SSW	Senior Supervisory Watch
STAR	Site Tracking, Analysis and Reporting
TRU	transuranic
WCMA	Warm Crane Maintenance Area
WIPP	Waste Isolation Pilot Plant
WAC	Waste Acceptance Criteria
WRT	Waste Remediation Technician (Technician)

1.0 INTRODUCTION

1.1 Background

On June 14, 2010, a Waste Remediation Technician (WRT or Technician) performing transuranic (TRU) waste remediation activities received a puncture wound to the right index finger while placing a hole indicating device (a wire survey flag) into a one-quart can to demonstrate that the can had previously been vented. The Technician was working in a special process enclosure within an Airborne Radioactivity Area / High Contamination Area / Radiation Area.

The Department of Energy (DOE) Savannah River Operations Office (SR) Acting Manager appointed a Type B Accident Investigation Board (Board) on July 28, 2010, to investigate the accident in accordance with DOE Order 225.1A, *Accident Investigations*. The appointment memorandum is included as Appendix A to this report.

1.2 Facility and Mission Description

Savannah River Site

The Savannah River Site (SRS) is a 310-square mile government-owned, contractor-managed facility near Aiken, South Carolina. Since August 1, 2008, DOE has contracted with Savannah River Nuclear Solutions, LLC (SRNS) for overall management and operation of Site activities.

F-Canyon

F Area is one of the two areas located near the center of SRS where nuclear chemical separations and waste management operations were performed. The original function of F Canyon was to recover special nuclear material from irradiated fuel targets. That mission has since ended and deactivation activities have been completed. Main systems still in use include cranes used for retrieval of F Canyon components, ventilation systems, electrical systems, fire pull stations, and elevators. The current state of the F Canyon complex is "Long-Term Surveillance and Maintenance."

TRU Waste Remediation

> **<u>TRU Waste and the Waste Isolation Pilot Plant</u>**
>
> "Transuranic" refers to elements with an atomic number greater than uranium (92). TRU waste is defined as waste contaminated with alpha-emitting TRU radioisotopes that have a half-life greater than 20 years and a concentration level above 100 nanocuries per gram.
>
> In 1999, DOE opened the Waste Isolation Pilot Plant (WIPP), a geologic repository in New Mexico specifically constructed for the permanent disposal of DOE TRU waste.

The TRU waste inventory at SRS includes waste generated at SRS and waste generated at other DOE sites and shipped to SRS for interim storage in E Area.

Waste shipped from SRS to WIPP must meet stringent WIPP Waste Acceptance Criteria (WAC) requirements. TRU waste drums identified by real-time radiography (RTR) as potentially containing items prohibited by the WIPP WAC, such as containerized liquids or aerosol cans, are processed in F Canyon to remove the prohibited items. Containerized liquids are immobilized using an appropriate absorbent and the remediated TRU waste drums are returned to solid waste management facilities for eventual shipment to WIPP.

Two areas within F Canyon are used to support TRU waste remediation. The Truckwell is being modified to support remediation of large containers, and the Warm Crane Maintenance Area (WCMA) is being used to support remediation of drums in a special process enclosure (Enclosure). The Enclosure was installed in the WCMA to allow TRU waste drums to be unloaded, examined, and remediated, as necessary (Figure 1-1). The Enclosure consists of a loading area, processing area, waste removal area and a wing cabinet. Unlike a glovebox which is sealed from the surrounding environment, the Enclosure has two openings. The drum loading area is open to the WCMA, and there is another opening above the bag-out area where tools and other items can be introduced into the Enclosure.

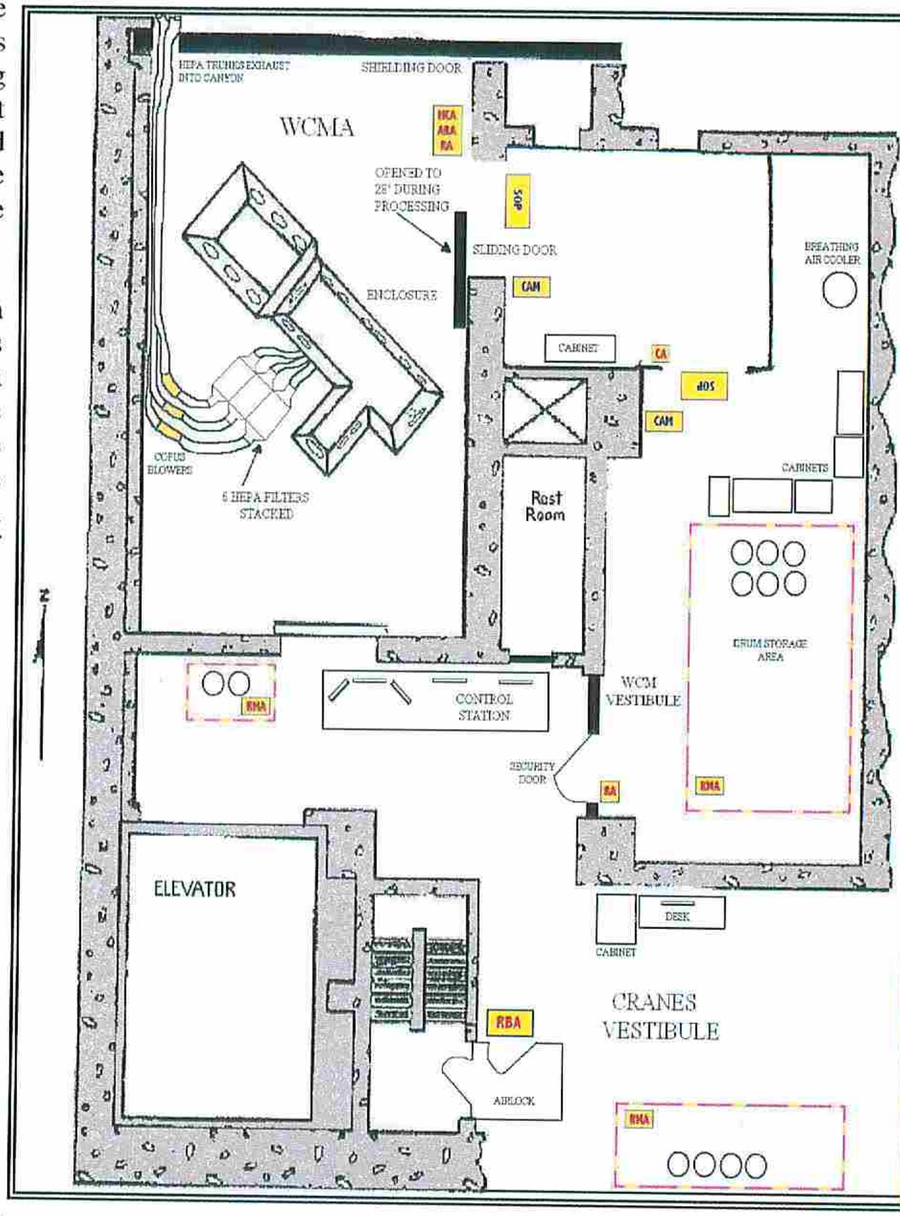

Figure 1-1. WCMA Layout

The processing area of the Enclosure is supported by a stainless-steel frame (Figure 1-2). The sides and top are constructed of a combination of flexible and rigid fire-retardant materials and the design includes additional features to prevent or mitigate fires. Based on the waste being processed, temporary shielding can be installed to minimize worker exposure. The Enclosure is ventilated by six blowers. Proper airflow is monitored by measuring the differential pressure across the Enclosure. The base of the processing area of the Enclosure is a stainless-steel tray-in-pan arrangement that can contain liquid spills of up to 15 gallons without affecting ventilation flow.

TRU waste containers requiring remediation are transferred from E Area to the WCMA Airborne Radioactivity Area / High Contamination Area /Radiation Area (ARA/HCA/RA). Work is conducted by Technicians, supported by Radiological Protection Inspectors (RPI). The 55-gallon waste drum is removed from its 85-gallon overpack container, if the overpack is present (Figure 1-3), and brought into the open end of the Enclosure. However, the 55-gallon drum may remain in the 85-gallon overpack, if conditions warrant. The lid is removed from the 55-gallon drum and, if present, the inner 30-gallon drum is removed and opened. The Technicians then address the non-compliant condition. Intact inner one-gallon containers are punctured with a shielded can puncturing device, checked for liquids, and the lids are removed. Quart-sized sealed cans within the one-gallon containers are also punctured with the puncturing device, checked for liquids, and a hole indicating device is placed into the opening to provide clear evidence that the can has been punctured when the containers later undergo RTR as part of final characterization activities prior to shipment to WIPP.

Figure 1-2. Enclosure

When remediation activities are completed, the waste materials from within the individual drum are placed into new 55-gallon drum(s), termed parent/daughter drums via the bag-out port. Daughter drums are created when the remediation process produces contents that will not fit into one drum. Daughter drums are created until the remediated contents are all contained. Due to assay requirements, parent/daughter drums remain together until they are assayed again. The new drums are sealed, radiologically surveyed, removed from the WCMA, and eventually transferred to E Area for final characterization activities and shipment to WIPP.

Current Campaign

TRU remediation activities previously conducted in the F Area WCMA were halted in October 2008. Preparations for the current campaign began in July 2009 with technicians and radiological protection inspectors hired under the American Recovery and Reinvestment Act (ARRA). As part of ARRA activities at SRS, SRNS was tasked with working with WIPP to complete disposition of 5,000 cubic meters of TRU waste from the SRS inventory. The scope includes approximately 2,500 containers of waste, most of which require remediation to comply with WIPP WAC requirements. The inventory contains over 350,000 curies of plutonium (Pu); Pu-238 is the radionuclide of concern in the majority of the inventory (Figure 1-4).

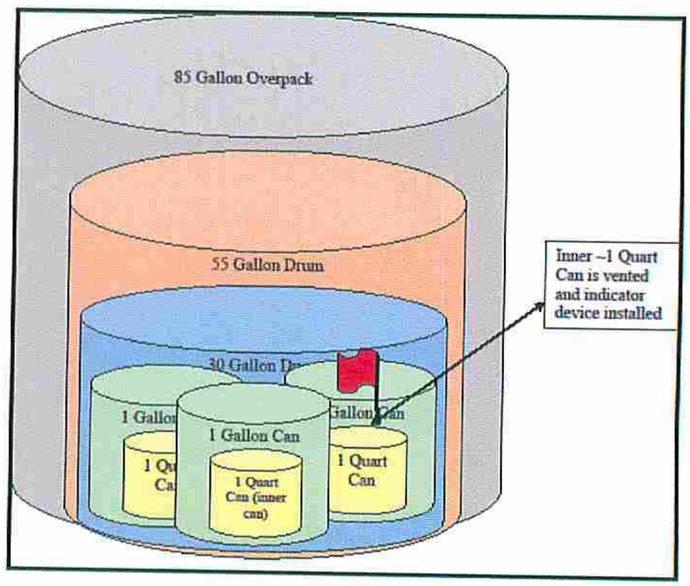

Figure 1-3. Typical Container Configuration

Plutonium-238	Plutonium-239
87 year half-life	24,000 year half-life
Heat source for remote power (e.g., Cassini Space Mission radioisotope thermoelectric generator)	Useful for nuclear weapons and reactor fuel
Fissionable but not fissile	Fissile (fission with thermal or fast neutrons) with criticality concerns
Spontaneous fission results in neutron exposures	Little neutron dose from spontaneous fission
Higher specific activity (curies/gram) = heat concerns	Low specific activity

Plutonium Hazards. Plutonium is chemically toxic to humans. Plutonium poses a health hazard only if taken into the body; Pu-238 and Pu-239 decay by emitting an alpha particle. Alpha particles are considered an internal hazard because the particles deposit large amounts of energy in a short distance of travel and thus have a high linear energy transfer. Because of the alpha particle's short range and large mass, it is not considered a hazard outside the body, as it will not penetrate a dead layer of skin. The bone surfaces and liver are the primary target organs for alpha-emitting plutonium isotopes. Plutonium remains in the body for long periods of time - the biological half–life ranges from about 20 years (liver) to 50 years (bone).

Key Differences in Behavior of Plutonium-238 and Plutonium-239:

- Pu-238 is nearly 300 times more active than Pu-239
- Pu-238 oxide particles are thermally hot and do not absorb water
- Pu-238 oxide encountered was typically dry-milled to an average size of less than 2 microns

Figure 1-4. Relative Comparison of Plutonium-238 and Plutonium -239

1.3 Scope and Methodology

The Board began its investigation on July 28, 2010, and submitted the final report to the DOE-SR Acting Manager on September 1, 2010. The scope of the investigation included identifying the relevant facts; analyzing the facts to determine the direct, root, and contributing causes of the accident; developing conclusions; and determining judgments of need that, when implemented, should prevent the recurrence of the accident. The Board's scope also included addressing the role of DOE and contractor organization Integrated Safety Management Systems, as well as an analysis of the application of corrective actions resulting from similar events. The investigation was performed in accordance with Savannah River Implementing Procedure 225.1, *Accident Investigations*, based on the requirements of DOE O 225.1A, *Accident Investigations*, and DOE's workbook, *Conducting Accident Investigations*, Revision 2. As directed by the Acting Manager's Appointment Memorandum, the Board took advantage of investigative activities conducted by SRNS, where appropriate.

The Board conducted its investigation using the following methodology:

- Facts relevant to the accident were gathered through interviews, document reviews, and examination and testing of physical evidence, including inspection of the Enclosure where the puncture wound occurred.
- Event and causal factor analysis, barrier analysis, and change analysis techniques were used to analyze the facts and identify the causes of the accident.

- Based on the above analyses, judgments of need were developed to identify corrective actions to prevent recurrence of the accident.

Accident Investigation Terminology

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

Events and causal factors analysis includes charting to depict the logical sequence of events and conditions and the use of deductive reasoning to determine the events or conditions that contributed to the accident.

Barrier analysis reviews the hazards, the targets (people or objects) of the hazards, and the controls or physical and/or administrative barriers put in place to separate the hazards from the targets.

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

Judgments of Need are managerial controls and safety measures necessary to prevent or minimize the probability or severity of accident recurrence.

2.0 THE ACCIDENT

2.1 Accident Overview

On June 14, 2010, at 0635 hours, a pre-job briefing was conducted prior to the commencement of Procedure 221-F-55006, *TRU Drum Repackaging*. At 0940 hours, an RPI entered the WCMA Enclosure to perform pre-job surveys. At 1020 hours, WRTs (WRT-1, WRT-2 and WRT-3) entered the work area to perform TRU drum remediation activities. The 55-gallon drum to be remediated contained five one-gallon waste cans, each of which had a one-quart waste can in its interior. Drum remediation activities consisted of segregating prohibited items and liquids from the TRU waste items and repackaging the contents such that a drum meeting WIPP WAC requirements was produced. Cans were punctured so that prohibited items and liquids could be removed or remediated. A hole indicating device (wire survey flag) was placed in the hole in the inner can so that subsequent radiography would be able to verify that the can was punctured and not pressurized. At 1135 hours, WRT-1 reported via radio headset to supervision that he had punctured his hand while placing a hole indicating device into a one-quart waste can. Prior to placing the hole indicating device into the can, WRT-1 had bent the hole indicating device into a "U" shape to ensure it would not come out of the can after placement. The end of the wire survey flag, now pointing upward, penetrated WRT-1's personal protective equipment, including a leather lineman's glove, and punctured his right index finger. Work stopped and the RPI, WRT-2 and WRT-3 came to the aid of WRT-1 and helped him remove his hands from the enclosure gloves while minimizing the spread of radioactive contamination.

2.2 Accident Chronology

Timeline	Activity
February 2009	WIPP WAC requires "sealed containers >4 liters (nominal)" to be vented prior to shipping.
July 2009	Preparations for current campaign begin with workers hired under ARRA.
November 2009	Fast Scan (RTR) of the drums from E Area Pad 1 identifies liquid in containers as well as some inner cans bulging or split.
March 2010	TRU Project Manager concerned with bulging inner cans based on WIPP WAC which precludes pressurized containers.
3-07-2010	Per 2010-MFO-001567, cans were opened inside the Enclosure using a hammer-type chisel. Operations Manager discussed with Project Manager need for can puncturing device.
3-11 – 18 2010	Need for "hole indicator" identified so WIPP can verify cans are vented prior to shipment from SRS.
3-12-2010	Change to Documented Safety Analysis approves use of can puncture device.
3-12-2010	Campaign shifts from waste segregation to include puncture of outer and inner cans, if liquid was identified.
3-18-2010	Procedure 221-F-55006 (Rev. 31) revised to insert hole indicating device. Plastic wire tie is used; no specific method is defined.
3-25-2010	Insulated wire replaces plastic tie wrap as the hole indicating device based on suspected inability of RTR to see plastic wire tie.
~3-31-2010	Insulated wire recognized as potential sharp and inadequately rigid.
4-07-2010	Wire survey flags ordered as replacement for insulated wires for hole indicating device for cans.
4-16 – 23-2010	Operations stopped due to smoking can event.
4-16 – 23-2010	Workers briefed on use of wire survey flags and how to properly install them as hole indicating device.
4-23-2010	Operations restarted, survey flags used as hole indicating device.
5-04-2010	Procedure 221-F-55006 revised (Rev. 32) to insert hole indicating device.
5-13-2010	TRU Project Manager asks WIPP for technical basis for the expectation that containers <4 liters must be vented. TRU Project Manager determined to vent all cans due to difficulty in determining whether the cans were pressurized above atmosphere.
5-14-2010	Procedure 221-F-55006 revised (Rev. 33).
6-14-2010 0600 hours	Work reduced to two shifts due to reduction in workload.
0635 hours	Pre-job briefing held.
0940 hours	RPI entered work area to perform pre-work surveys
1020 hours	Personnel entered work area with one 55-gallon drum containing one 30-gallon drum which contained five one-gallon cans containing five one-quart cans.
1135 hours	While inserting the hole indicating device (survey flag) into one of the vented inner cans, WRT-1 punctured his right hand with the survey flag.
1140 hours	The Shift Operations Manager was notified that a puncture wound had occurred in the WCMA.
1155 hours	Savannah River Site Operations Center (SRSOC) contacted. Radiological Protection First Line Manager notified (paged) Internal Dosimetrist.
1202 hours	Emergency Management Services personnel arrive at the worker, RPI survey indicated 300 dpm alpha contamination at the wound.
1208 hours	Emergency Management Services personnel left scene enroute to N Area with WRT-1.
1217 hours	Emergency Management Services personnel and WRT-1 arrive at 719-5N.

2.3 Emergency Response

At approximately 1135 hours on June 14, 2010, WRT-1 felt that he had punctured his hand with the hole indicating device (wire survey flag) he was inserting into a punctured TRU waste can. WRT-2, WRT-3 and the RPI assisted WRT-1 in removing his hands from the Enclosure gloves and performing the required monitoring. Proper actions were taken to seal a bag over the punctured Enclosure glove to preclude the release of contamination into the room. A survey was conducted of the outer surgical glove and the glove was determined to have 1000 disintegrations per minute (dpm)/100 cm^2 alpha and no detectable beta gamma. The outer surgical glove was removed and no detectable contamination was found on the inner glove. WRT-1 was processed out of the ARA/HCA/RA and then out of the Contamination Area. Using a direct probe the RPI surveyed the wound area on the right index finger and found 300 dpm alpha. A clean rubber surgical glove was used to cover the wounded hand and WRT-1 was escorted downstairs and processed through the personnel contamination monitor (PCM)-1B where he was monitored twice and cleared both times. The Savannah River Site Operations Center (SRSOC) was contacted at 1155 hours by the F Canyon Shift Operations Manager to report a puncture wound in a contaminated area on the right hand of the injured person. SRSOC alerted Station 1 at 1157 hours. Medic 3 from Station 3 was also dispatched at 1157 hours. Station 1 (Station Chief [F-1], Engine 4 [E-4] and Medic 4 [M-4]) were in route within 1 minute. Medic 3 (M-3) was in route at 1201. M-4 arrived in F Area at 1201 followed by M-3, F-1 and E-4 at 1202. At 1205, N Area medical was contacted by Fire Dispatch to confirm that the inbound patient was contaminated. At 1208 hours, M-4 was in route to N Area medical with one RPI onboard. At 1210 hours, SRSOC contacted the F Canyon Shift Operations Manager who stated that the initial wound count probe was 150 counts per minute alpha (300 dpm) on the right index finger. At 1210 hours, F-1 terminated command and returned to Station 1 along with E-1. At 1217 hours, M-4 arrived at N Area medical with the patient.

In reviewing radiological survey records for the accident, the Board determined that a subcontract RPI performed a transferable contamination survey (smear) of WRT-1's hand around the wound during the initial accident response (no transferable contamination was found). This action was not in compliance with Procedure 5Q1.2, 203, *Handling of Radiological Injuries, Contamination Cases, and Suspected Intakes of Radioactive Material.* The procedure directs probe surveys of personnel, not smears, as smears could facilitate embedding contamination in the worker's skin.

Prior to the patient arriving at N Area Medical, medical personnel initiated Procedure Q3.7-5001, *First Aid and Nursing Procedures* (a "use every time" procedure). Procedure Q3.7-5002, *First Aid and Nursing* (a technical reference procedure) was also used during this event. Upon arrival of the patient at N Area medical, medical personnel began cleaning the wound under the supervision of the RPIs, using water which was collected in a basin. The cleaned area was dried and contamination levels remained the same (300 dpm alpha). The nurses continued to attempt to decontaminate the wound using Go-Jo wipes provided by the RPIs. The cleaned area was dried and a slight decrease in activity levels (250 dpm alpha) was detected. The use of soap decreased the contamination levels to 200 dpm alpha. A second cleaning with soap resulted in no further reduction in contamination. At approximately 1252 hours, the site doctor removed a flap of skin and the area of the wound still probed 200 dpm alpha. At this time, the doctor discussed the use of chelation therapy with WRT-1 and the patient provided his consent to be administered the chelating agent (see insert next page). At approximately 1258 hours, 83 minutes after the accident, WRT-1 was administered the first dose of chelating agent (calcium diethylenetriaminepentaacetate (Ca-DTPA)) intravenously. WRT-1 was transported to the Whole Body Count facility at 1302 hours for a wound count. At approximately 1323 hours, a ten-minute wound count revealed Pu-238 and americium-241. WRT-1 was returned to N Area medical where the site doctor performed a tissue punch (approximately 3 mm in diameter) to excise tissue from the wound along the projected wound path. Following the tissue punch, the RPI surveyed the wound with a hand-held detector and determined the activity level to be less than 200 dpm. Records indicated that this tissue punch was the most successful, removing roughly 14,000 dpm of Pu-238 (per a count performed on the removed tissue by the Savannah River National Laboratory (SRNL) at a later date). WRT-1 was transported back to the Whole Body Count facility where a second wound count was performed at approximately 1450 hours. The activity was slightly less than half that observed by the first count. WRT-1 was returned to N Area medical. After consulting with Internal Dosimetry personnel, the attending physician determined that a second excision was needed and should be performed by a designated off-site specialist. The off-site specialist arrived at N Area medical at approximately 1715 hours. The second excision was performed at approximately 1815 hours, after which three stitches were applied to the wound area and WRT-1 was transported back to the Whole Body Count facility. A third ten-minute wound count began at approximately 1842 hours. Information provided by a SRNL evaluation of the extracted material indicated that approximately 3,200 dpm was removed during this excision. At this time, the need to collect every urine void was discussed with WRT-1. WRT-1 was provided the materials needed to collect bioassay samples and released to return to his local residence. On Day 9, a third excision was performed by the off-site specialist at N Area medical. This excision resulted in the removal of approximately 3,800 dpm from the wound area according to SRNL evaluation of the extracted material. No further excisions were performed because the results showed only a small amount of activity was removed and the specialist determined that additional excision could result in damage to the tendon sheath and/or neurovascular bundle (Figure 2-1).

> **Chelation** means to "bind" or to "grab". In chelation therapy, chelating agents/drugs such as diethylenetriamine-pentaacetate (DTPA) are administered by medical professionals to bind transuranic materials in the bloodstream. DTPA therapy has been used since 1958. The mechanism of action for DTPA is to "exchange" the associated calcium or zinc salt with an element of higher binding power such as plutonium or americium and form a stable "chelate" complex. Once this chelate is formed, it is quickly transported to the renal system where it is promptly cleared via urinary excretion. Because of this action, the agent is most effective if immediately administered after an intake. The efficiency of the chelation process is dependent on the solubility and retention properties of the transuranic material. Calcium DTPA is about 10 times more effective than Zinc DTPA for initial chelation of transuranics. Twenty-four hours after exposure, Zinc DTPA has comparable efficacy coupled with lesser toxicity, and is thus preferred for continued therapy treatments.

Figure 2-1. Technician's Hand after Third Excision

Chelation therapy was not administered on the second day due to issues related to the availability of the patient and bioassay analysis results. Chelation (switching from Ca-DTPA to Zn-DTPA for long term treatment) was administered daily from Day 3 until Day 16. Chelation was not administered from Day 17 to Day 22 because WRT-1 returned to his permanent residence out-of-state. The WRT returned to the area on Day 23 and on Day 24 the decision was made to reduce chelation therapy from daily to twice weekly.

At the time of this report, chelation treatments are expected to continue until no measurable improvement is identified. Bioassay samples continue to be collected with results being tracked and trended to help determine when to discontinue the chelation therapy. SRS doctors continue to perform blood panels to monitor the patient's vital body functions, and have advised the patient to take a multi-vitamin due to the possible loss of trace minerals resulting from chelation therapy.

The Board determined that instructions were not given to WRT-1 on controlling bioassay voids to minimize contamination of others. The Board directed the contractor to notify WRT-1 about the precautions included in the "Information for Patients" listed on the package insert for the use of the DTPA chelating agent. The precautions give specific guidance on controlling voids to prevent the spread of contamination.

The Board also determined through interviews that after WRT-1 was transported to the Whole Body Count facility at 1302 for a wound count, Radiation Emergency Assistance Center/Training Site (REAC/TS) personnel from Oak Ridge recommended that the site doctor inject the chelating agent directly into the wound. The site doctor chose not to administer the drug in this manner as this was not a recommended means of administration according to the drug manufacturer. The Board recommends that the Site Medical Department discuss with REAC/TS alternate means of administration of the chelating agent (e.g., injecting directly into the wound) to determine if there are benefits to this treatment therapy (OFI).

REAC/TS personnel reviewed the overall medical response and treatment regiment related to this accident and provided generally positive comments. However, they did note that failure to administer the chelating agent on Day 2 resulted in a missed opportunity to remove an additional approximate 0.5 rem Committed Effective Dose (CED) from the worker (OFI).

The Board also noted that there was no location within the N Area Medical facility that was permanently identified as the location for the treatment of contaminated wounds. While the Board found no evidence that treatment of the patient in this accident was impacted by the lack of a dedicated location, medical personnel stated that a room dedicated to contaminated wound treatment would enhance overall treatment of patients (OFI).

The Board concluded that the overall emergency response and the treatment actions provided during this accident were adequate. However, the Board also concluded that initial radiological protection survey techniques were not in compliance with SRNS Manual 5Q, Radiological Control, and the patient was not informed of proper contamination control techniques associated with collection of bioassay voids.

2.4 Dose Assessment

An intake of radioactive material was confirmed after multiple wound counts and multiple bioassay sample analyses. The Board determined that WRT-1 was injected with approximately 40 nanocuries of transuranics including Pu-238 and americium-241. Pu-238 was determined to be the main radionuclide of concern in this accident. WRT-1 began receiving chelation therapy and tissue excisions shortly after the injury to facilitate removal of transuranics from his body.

After repeated requests from the Board, SRNS provided an initial range (low and high) projection of the worker's final dose on August 9, 2010. The range was estimated to be between 5 and 50 rem CED to the whole body and between 166 and 1657 rem committed equivalent dose to the bone surface from this intake. SRNS initially declined to release any dose estimates until determining the Technician's final dose, which will not be determined until a minimum of 100 days have elapsed following the final chelation. Chelation therapy is recommended until excretion of Pu-238 falls significantly. As a result, it is estimated that the Technician's final assigned dose will not be determined until 2011. At the time of this report, at least 25 rem CED had been eliminated by tissue excisions and multiple chelation therapies.

Based on the dose projections provided, it is indeterminate whether this event met the threshold for a Type A Investigation.

DOE Order 225.1A , *Accident Investigations,* provides the following criteria for determining whether an accident requires a Type A or Type B investigation:

- Type A investigations are required for accidents involving a total effective dose equivalent (including a committed effective dose) of 25 rem or more; or a committed equivalent dose to any organ or tissue other than the lens of the eye of 250 rem or more.
- Type B investigations are required for accidents involving a total effective dose equivalent (including a committed effective dose) of at least 10 rem but less than 25 rem; or a committed equivalent dose to any organ or tissue other than the lens of the eye of at least 100 rem but less than 250 rem.

Timeliness is crucial to conducting an effective investigation, preserving the accident scene and evidence, and identifying causal factors. Dose mitigating activities such as multiple chelation therapies, multiple wound decontaminations, and multiple tissue excisions to reduce the dose could take from several months to up to a year. These actions are important to ensure the safety and health of the worker, but should not have any role in delaying the initiation of an investigation.

The Board found that based on past accident investigations, the decision to initiate an investigation was based on an estimate of the dose that would have resulted in the absence of medical intervention. Two external experts (a REAC/TS specialist and an MJW Technical Services internal dosimetrist) came to the same determination. In contrast, the initiation of an accident investigation for this event was not determined based on initial unmitigated dose projections. Mitigating actions of multiple decontamination efforts, multiple chelations, and multiple surgeries were performed prior to the contractor releasing estimated dose projections.

The Board concluded that SRNS's reluctance to share the dose projections from the initial intake impacted DOE's ability to categorize this event in a timely manner based on dose.

2.5 Investigative Readiness and Accident Scene Preservation

DOE O 225.1A, *Accident Investigations*, requires contractors to establish and maintain readiness to respond to accidents, mitigate the consequences, assist in collecting and preserving evidence, and assist with the conduct of the investigation. This includes preserving the accident scene while it is under the contractor's control and documenting the accident scene through photography and other means. SRNS implements these requirements through a variety of documents, including:

- Manual 9B, *Site Item Reportability and Issue Management* (SIRIM) Procedure 1-0, Rev. 4, effective September 7, 2007. This procedure requires action to be taken to preserve conditions for continued investigation and documenting the accident scene, as appropriate, where these actions do not interfere with establishing a SAFE CONDITION.
- Manual 2S, *Conduct of Operations*, Procedure 5.2, Rev. 9, effective September 2, 2008, outlines the procedure for issue investigation, involving ensuring that equipment, systems or

areas are quarantined as necessary in order to preserve evidence, minimize further equipment damage, and/or prevent personnel injury.

- Manual 8Q, *Employee Safety,* Procedure 8Q-18, Revision 9, effective June 24, 2003, Attachment B, "General Investigating Guidance for Injuries/Illnesses." The attachment includes guidance on accident scene preservation, such as: "Safeguarding of evidence… is essential to the investigation."
- Manual SCD-7, *SRS Emergency Plan,* Section 9, Rev. 6 effective February 6, 2009, "Recovery and Reentry", contains requirements for control of the accident scene such that it will be preserved until the cognizant investigative authority concurs that recovery or normal operations can be resumed.

During the accident investigation, the Board noted the following facts regarding SRNS's accident investigative readiness.

On June 17, 2010, the contractor entered the WCMA and Enclosure. The evolution was video recorded for use in future investigations, if necessary. During the June 17, 2010, entry, remediation of the drum contents was resumed to enable SRNS to place the Enclosure in a safe configuration and allow the required fire watch to be suspended. During this entry, evidence consisting of the leather lineman's glove, enclosure glove, surgical gloves, and the survey flag used as the hole indicating device was collected. One drum containing the gloves and the hole indicating device was produced and staged in the WCMA. The drum and waste contents that were undergoing remediation at the time of the accident were processed and shipped to E Area.

On July 19, 2010, a second entry was made to remove an accumulation of unneeded tools and tools with sharps from within the Enclosure. These tools were drummed and staged in the WCMA and the evolution was video-recorded for future use. The Board determined that this second entry was not immediately justified to place the facility in a safer configuration. The entry resulted in the removal of evidence from the scene of the accident that should have been preserved pending a formal accident investigation determination by DOE. As a result, the accident scene was not formally preserved and turned over to the Board as required by DOE Order 225.1A. The Board subsequently required that the contractor place tamper-indicating seals/tape on three drums to ensure accountability while observation and testing arrangements were being made in support of the investigation. In accordance with a plan developed by the Board, SRNS later reintroduced the drum containing the prime evidence (gloves and survey flag used as a hole indicating device) into the Enclosure for the Board's visual inspection.

DOE-SR Savannah River Implementing Procedure 225.1, *Accident Investigations,* Rev. 3, Section 6.1.2 requires the DOE-SR Cognizant Assistant Manager/Office Director to ensure that DOE and contractor readiness response actions taken immediately following an accident will secure, preserve, and document the accident. Through interviews, the Board determined that DOE-SR Assistant Manager for Nuclear Material Stabilization Project personnel were aware of the contractor entries into the Enclosure prior to securing the accident scene, but failed to stop the contractor from removing the evidence.

The Board concluded that DOE-SR failed to ensure that the contractor maintained adequate control of the accident scene prior to arrival of the Accident Investigation Board as required by procedure.

The Board also concluded that SRNS did not preserve and control the accident scene prior to turnover to the Board in accordance with DOE O 225.1A and SRNS procedures.

2.6 Examination of Evidence

Initial recovery activities for the remediated waste, the enclosure glove, the leather lineman's glove, and the hole indicating device (survey flag) from the June 14, 2010, accident were performed on June 17, 2010. SRNS, with acknowledgment from the DOE Assistant Manager for Nuclear Material Stabilization Project, video-recorded the recovery evolution. The Board reviewed this video. SRNS also executed Procedure 221-F-55029 on July 19, 2010, to perform a tool and supply inventory evaluation involving safety, facility management, and engineering personnel to determine whether the tools were safe for use in the Enclosure. SRNS provided a detailed video recording of the second evolution. The Board compared the approved procedure inventory list to the video evidence and no discrepancies were noted.

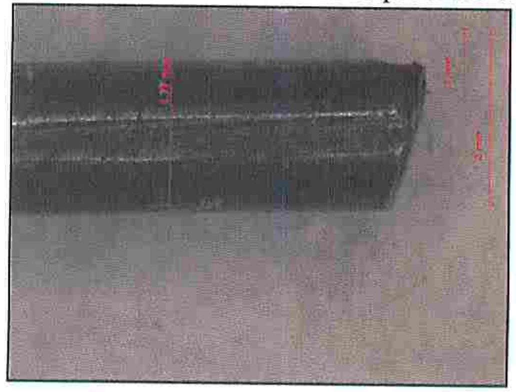

Figure 2-2. Survey Flag Tip

The Board developed an Inspection Plan to observe the physical condition of the hole indicating device (wire survey flag), the leather lineman's glove, the enclosure glove, surgical gloves, the Enclosure, and the WCMA. The Inspection Plan also included a request for laboratory analysis and photographing of the lineman's glove and the hole indicating device to be performed by SRNL (Appendix F). The Inspection Plan included a Board member entering the WCMA ARA/HCA/RA where the Enclosure is located to visually inspect the items while a second Board member observed the operation remotely through three cameras positioned in the WCMA. On August 12, 2010, the evidence items were placed back into the Enclosure for inspection. Of the three cameras in the area, only the camera located adjacent to the bag-out port within the Enclosure is equipped to allow video recording. This camera was used to record the inspection of the items listed above. All items inspected were viewed through a magnifying lens and photographed.

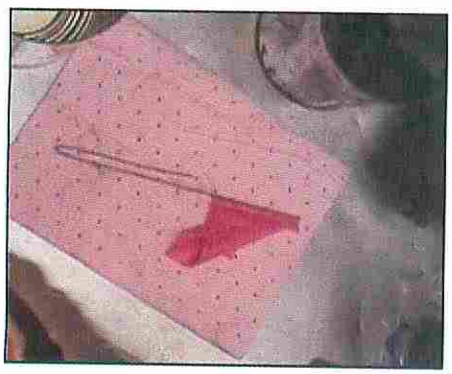

Figure 2-3. Modified Survey Flag

The Inspection Plan for the hole indicating device (survey flag) included steps to determine the length of the flag, inspect the tip/end causing the puncture wound, and the shape and physical condition of the flag. The Board found that the flag was shorter than the 20-¾ inch manufactured length. The flag tip was viewed through a magnifying lens and appeared to have a pointed edge vice a blunt end. The flag was sent to SRNL for analysis to determine whether the flag was cut, using digital photography under a microscope (Figure 2-2). The Board also observed that the flag was bent at a 180 degree angle (i.e., it was "U" shaped) so that the bottom end/tip of the flag was just below the flag (Figure 2-3). The Board did not observe any obvious signs of corrosion from hazardous/chemical exposure.

Figure 2-4. Lineman's Glove

The leather lineman's glove was inspected to determine the location of the hole, observe for chemical and physical damage, and to determine whether the flag caused the puncture hole. The glove was also sent to SRNL for analysis to determine whether the glove had been subjected to degradation from chemical and radiation exposure. The Board observed that the location of the puncture hole in the glove was in the palm just below the right index finger (Figure 2-4). The glove was heavily soiled/stained. There were no signs of additional punctures, cuts, or abrasions on the glove. An attempt was made to insert the flag back into the puncture hole to ensure it was the item that caused the puncture, but this was unsuccessful due to difficulties the Technician had trying to use hand tools to hold the flag and glove. The glove was also turned inside out to observe the physical condition of the interior. The Board did not observe any obvious stains, markings, or signs of degradation.

The Enclosure glove was inspected to determine the location of hole, manufacturing specifications to verify thickness, and the physical condition of the glove (Figure 2-5). The puncture hole was difficult to locate due to its elasticity and was identified just below the right index finger. The glove exterior was white in the hand area that was covered with the lineman's leather glove. Above that area the glove was discolored (brownish). The glove appeared to be heavily used but the Board did not observe any obvious signs of degradation. The inside portion of the glove was blue. This glove was determined to be a 20 mil glove.

Figure 2-5. Enclosure Glove

The surgical gloves and the cotton liner were inspected to determine the location of the hole and the physical condition. This inspection was conducted outside of the Enclosure but within the WCMA. The Board expected to observe three punctured gloves, the number required by the Radiological Work Permit (RWP), but found that only one glove and the cotton liner were observed to be punctured. (Through interviews, the Board determined later that WRT-1 was only wearing two pairs of surgical gloves. Only one of the two pairs was found in the examination of evidence.) Both the surgical glove and the cotton liner were punctured in the right index finger near the palm. The surgical glove had a stain approximately one-half inch in diameter at the puncture site inside the glove (Figure 2-6). The punctured cotton liner was heavily stained with what appeared to be blood. The Board also observed an additional four pairs of surgical gloves that were collected along with the punctured glove. One of these additional surgical gloves had a small stain located in the palm but no puncture. A leak test was performed in an attempt to identify a small hole in these additional pairs of gloves, but no leakage (puncture) was observed.

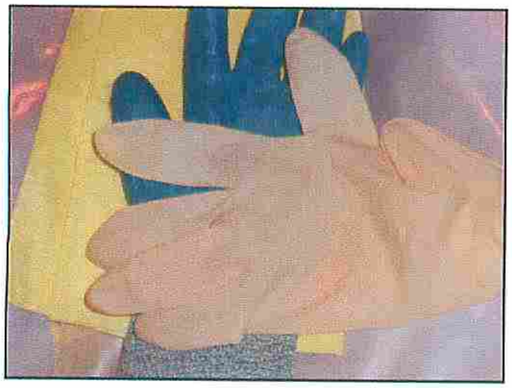

Figure 2-6. Punctured Surgical Glove

The Board concluded that WRT-1 was not wearing all of the prescribed PPE required by the RWP.

The WCMA and the Enclosure were also inspected to determine their overall condition and to observe whether any prohibited/sharp items remained in the area. The Board observed that the stainless steel enclosure tray was heavily dented but did not appear to have any holes. The Board also found numerous housekeeping issues, discussed further below.

Housekeeping

While conducting the examination of evidence, the Board found that the WCMA working spaces were significantly deficient in housekeeping and contained vast amounts of unneeded materials (OFI). The condition of the room presents a general safety hazard to the workers in the area. Workers in WCMA have not brought the condition of the room to management's attention revealing a lack of understanding of the room's hazards by the work crews. The Board found no evidence that anyone other than the work crews had entered the WCMA (including management, start-up assessment teams, or the Facility Evaluation Board). An opportunity to identify and remediate the condition of the room was missed by the lack of management presence in the work area.

Conditions found in the WCMA by the Board included:

- Many sharps readily available for possible re-introduction into the Enclosure. This included three survey flags observed under the radiological control supply cart. Two of the three flags were shorter than 20-¾ inches.
- Extraneous tools similar to those prohibited in the Enclosure.
- Numerous items not needed for the TRU drum remediation workscope, including scaffolding parts, a scissors man-lift, and toolboxes.
- Inadequate labeling and storage of secondary containers for chemicals.
- Duct tape covering an apparent hole in the wall of the Enclosure.
- Outdated inspection stickers on enclosure gloves.
- No control of lead blanket(s) lying on the floor.
- Ventilation equipment (Mac21) completely wrapped in yellow plastic (out of service).

Procedure 221-F-55029 was performed on July 19, 2010, to conduct an inventory of tools in the Enclosure, eliminate tools that were no longer needed or damaged, and to eliminate unnecessary sharps. The Board observed a video of this evolution and observed an excessive amount of extraneous tools, and unused and damaged equipment located in the Enclosure. The Board determined that routine housekeeping of the Enclosure had not regularly been performed.

SRNL Laboratory Results

The Board requested that SRNL develop a test plan and perform analysis of the leather overglove and the hole indicating device used in the Enclosure by the Technician at the time the accident occurred. Appendix F contains the test plan and Appendix G contains the results of the analysis. The following is a brief summary of the analysis performed by SRNL.

- Radiological evaluation of the leather glove to determine the level of radioactivity as received from the F Canyon Enclosure. This information was used to assess the level of radiological degradation.
- Documentation of the overall condition of the glove, both visually and under a calibrated stereoscope using digital photography. The glove was examined in various orientations and magnifications to determine its overall condition; surface texture; and examine in depth the puncture area. Both new gloves and the glove used during the accident were examined for comparative purposes.

- A representative section of the glove was taken and used to perform Fourier Transform Infrared and Raman spectroscopic analysis to identify chemical species present on the gloves, as well as analyzing the chemical/molecular structure of the leather. Both new gloves and the glove used during the accident were examined for comparative purposes.
- The hole indicating device used during the accident was visually examined, digitally photographed, and measured (diameter and length).

SRNL provided the final results of its analyses to the Board on August 30, 2010. Key facts include the following:

- The middle finger of the lineman's glove was surveyed and found to contain transferable contamination levels of 36,000,000 dpm alpha on the palm side and 17,000,000 dpm alpha on the fingertip. The glove exhibited total activity of 5,600,000,000 dpm, with the majority of the activity due to Pu-238.
- The survey flag used as the hole indicating device that caused the puncture wound in this accident was 16.625 inches in length and 0.068 inches in diameter.
- The end of the survey flag was angled relative to the squared end of a new survey flag. This would allow the glove to be punctured more easily than a new survey flag, since the angled end allowed for a combination of cutting and shearing of the leather, while a square end would act primarily in a shearing mode. This effect would be expected to reduce the penetration force of the survey flag involved in the accident versus a new survey flag.
- Chemical analysis of the glove used during the accident and a new glove did not reveal any chemical difference between them. The glove used during the accident did show signs of heavy use. This glove did have signs of dirt/grime on it from silica, rust, and uranium. Areas of this glove that did not show discoloration were essentially the same as a new glove. Overall, there was no evidence of degradation significant enough to cause detectable loss or change in puncture resistance.

The Board had also proposed that SRNL perform puncture and leach testing on the gloves. However, on August 27, 2010, SRNL proposed, and the Board agreed, to cease testing and finalize the results of their analysis. This was due to the belief that chemical leaching and puncture testing the leather gloves (both new and the one used during the accident) would not provide any additional information given the lack of evidence that the radiological and chemical environment the glove used during the accident was subjected to contributed to its being punctured. Other than evidence of dirt/grime and some discoloration below the dirt/grime, the glove used during the accident was physically and chemically similar to a new leather glove.

The Board concluded that a shortened (cut) survey flag allowed WRT-1's glove to be punctured more easily than a new survey flag.

3.0 ACCIDENT FACTS AND ANALYSIS

3.1 SRNS Integrated Safety Management Processes

The Board considered the facts related to the accident and its analyses of the accident and has correlated this information to the Integrated Safety Management (ISM) Core Functions. The ISM Core Functions comprise the fundamental DOE safety and health policies that should be incorporated into all work planning and execution activities. The five ISM Core Functions are designed to ensure that safety is effectively considered and implemented during all phases of work activities. The failure of any one of the core functions will result in the failure to effectively accomplish subsequent core functions. For example, if the specific work scope to be accomplished is not clearly and effectively identified, or if work scope changes are not recognized, the task-specific hazards associated with the specific work scope cannot be properly identified.

The DOE Integrated Safety Management System (ISMS) is described in DOE P 450.4, *Safety Management System Policy*. SRS's ISMS implementation is described in SRNS-RP-2008-00087 Rev. 1, *Integrated Safety Management System Description*, August 24, 2009. The ISMS Description document is part of the Standards/Requirements Identification Document (S/RID) which is part of DOE Contract DE-AC09-08SR22470. The SRS ISMS Description document was initially approved in 1997 and the certified system was adopted by the current Management and Operating contractor (SRNS) in 2008. The ISMS applies to work performed by SRNS and work performed by SRNS subcontractors when required by subcontract or applicable law.

There are three primary regulations associated with the work being conducted during which the accident occurred. From a radiological perspective, 10CFR835, *Occupational Radiation Protection*, is invoked in the SRNS contract and incorporated in the S/RID. The S/RID identifies the primary implementing procedure as Manual 5Q, *Radiological Control*, and its implementing procedures. From an occupational safety perspective, 10CFR851, *Worker Safety and Health Program*, is invoked in the SRNS contract and incorporated in the S/RID. The S/RID identifies the primary implementing procedure as Manual 8Q, *Employee Safety Manual*, and its implementing procedures. The area where the work was being conducted is a posted beryllium enclosure system, and 10CFR850, *Chronic Beryllium Disease Prevention Program*, is applicable as noted in 10CFR851. This requirement is invoked in the SRNS contract and the S/RID and implemented in Manual 4Q, *Industrial Hygiene Manual*, and its implementing procedures.

The Board concluded that the commitment to comply with ISMS and regulatory requirements was adequately captured in contract documents and Site-level procedures.

3.2 Define the Scope of Work

Effective work execution begins with the development of a well-defined scope of work that translates mission and requirements into terms that those who are to accomplish the work can clearly understand. Defining the scope of work is the first core function of an effective ISMS program. A well-defined scope of work is required for successful completion of the ISM core functions that follow, including hazard analysis and development and implementation of controls. Line management must determine the work to be accomplished and be accountable for completely understanding the scope through every phase of the work cycle.

The DOE strategy for the disposition of TRU waste includes the shipment of TRU waste from the generator sites to WIPP in Carlsbad, New Mexico. The TRU waste currently being remediated is located on Pad 1 in E Area and primarily contains Pu-238. SRS discussed various storage strategies with the Environmental Protection Agency and the South Carolina Department of Health and Environmental Control (SCDHEC). SCDHEC supports SRS plans to ship as much of the Pad 1 waste as possible to WIPP using existing facilities. Alternate storage options such as monitored long-term storage have been discussed, but no final agreements have been made to date.

The current phase of the TRU remediation work involves Pad 1 drums. These drums range up to 1,800 plutonium equivalent curies. This accident involved a 328 curie drum. The Board found that no risk analysis had been performed for conducting the remediation work in an Enclosure versus other alternatives. As a result, the Board could not evaluate the basis for choosing to conduct the TRU drum remediation work in an Enclosure. A formal evaluation of the risk of continuing work in an enclosure for higher curie drums versus alternative paths should be completed (OFI).

The Pad 1 TRU waste consists of waste generated at SRS and waste generated at other sites and shipped to SRS for interim storage. The waste is remediated and repackaged in the F Canyon WCMA Enclosure to ensure that the waste containers meet the final disposition requirements in the WIPP WAC. The WIPP WAC requires TRU waste drums to be free of containerized liquids, pressurized cans, and other prohibited items; a waste certification official documents and certifies the waste containers meet all requirements.

TRU waste containers requiring remediation are transferred to the F Canyon WCMA ARA/HCA/RA. The original 55-gallon waste drum is removed from its 85-gallon overpack container, if the overpack is present, and brought to the Enclosure for lid removal and introduction to the Enclosure. However, the 55-gallon drum may remain in the 85-gallon drum, if conditions warrant. The lid is removed from the 55-gallon drum, and if necessary, the Technicians remove the inner 30-gallon drum and pry the lid off. The Technicians then address the non-compliant condition, such as the presence of liquids or sealed inner containers. Intact inner one-gallon containers are punctured with a shielded can puncturing device, checked for liquids, and the lids are removed. Quart-sized sealed cans within the one-gallon containers are also punctured with the shielded can puncturing device, checked for liquids, and a hole indicating device (wire survey flag) is placed into the opening to provide clear evidence that the can has been punctured when the containers later undergo RTR as part of final characterization activities prior to shipment to WIPP. When remediation activities are completed, the remediated waste is placed into a new 55-gallon drum connected to the Enclosure through a bag-out bag. The new drum is sealed, radiologically surveyed, and removed from the WCMA.

WRTs assigned to conduct work in the Enclosure must meet the personal protection equipment (PPE) requirements listed on RWP 10-SWM-123, Task 1. This RWP requires two pairs of coveralls (OREX can be worn as the outer pair of coveralls), one pair of cotton glove liners, three pairs of surgical gloves, one pair of cloth booties, three pairs of plastic shoe covers, one cloth hood, and a fresh air hood. Additional PPE is also required to address non-radiological hazards (discussed further in Section 3.4 below).

In this accident, the work was defined in Procedure 221-F-55006, *TRU Drum Repackaging*, Rev. 33, which is a "use every time" procedure. Issues with this procedure had been previously identified by DOE and SRNS, but corrective actions were not effective. The Board found that while many aspects of the work were defined, and the procedure had been revised numerous times to incorporate comments, the procedure still contained vague and conflicting information on the work to be performed, which is contrary to guidance provided in SRNS Manual 2S, *Conduct of Operations*. For example:

- Step 4.1.43 states that the drum dumper should be decontaminated at 1,000,000 dpm/100 cm^2 alpha, whereas Radiological Work Permit RWP-10-SWM-123, "Specific Radiological Conditions," states that decontamination of the drum dumper should begin at 400,000 dpm/100cm^2 alpha.
- Step 3.0.5 states that workers should "Review RTR data for the drums to be processed" but fails to identify what the review should encompass.
- The procedure lacks instructions on characterizing liquids that may be present in the drums or containers, stating only that workers should take a pH reading and contact Engineering and Supervision if the pH is less than 5. In this case, neutralization with sodium hydroxide is normally prescribed per Procedure 221-F-55012. Without characterization of the liquid to

determine chemical makeup, accurate and effective PPE to abate the various hazards cannot be effectively prescribed.

- The NOTE prior to step 4.1.25.f.4 states that "Sealed containers less than or equal to 4 liters containing no liquids are NOT required to be opened". This conflicts with step 4.1.25.f.5.H which states that all inner containers (1 quart) should be punctured.
- The procedure did not provide specific directions on the proper technique for inserting the hole indicating device into the punctured can. The Board found that at least five different techniques were developed by the Technicians to ensure that the hole indicating device remained inserted into the can.

The "Precautions and Limitations" section of the procedure stated that workers should use tools instead of their hands when performing waste handling and repackaging inside the Enclosure, and warned that sharps could be encountered when performing waste remediation activities. Based on interviews, the Board determined that various workers (including RPI, WRTs, and First Line Managers) did not recognize the survey flag to be a hazard to the workers because they did not consider that the device could penetrate the various layers of PPE worn by the WRTs.

Evidence indicates that "sharps" were discussed during the pre-job briefs. However, because the hole indicating device (survey flag) was not considered to be a hazard to the workers, potential hazards and controls were not adequately discussed with the workers for this specific work activity.

The Board concluded that the scope of work for the remediation and repackaging work was not fully defined and the methods used to ensure the development of procedures compliant with SRNS Manual 2S, Conduct of Operations, had not matured.

3.3 Analyze Hazards

The objective of the hazards analysis process is to develop an understanding of task-specific hazards that may affect the worker, the public, or the environment. Each level of hazard analysis forms the foundation for a more detailed analysis. Hazard identification and analysis must occur at any phase of the work cycle to which it applies, and is dependent upon the adequate and full definition of the activity or task to be performed. If the activity or task is not fully identified or defined, an adequate task-specific hazard analysis cannot be performed.

SRNS Manual 8Q, Procedure 122, *Hazard Analysis*, provides the overall requirements for analyzing hazards and the subsequent development of controls. Hazard analysis for the TRU waste repackaging campaign had been performed in various stages since 2007 under procedures containing controls derived via Assisted Hazards Analysis (AHA) FCA-4160. Revision 4 of that AHA authorized work to begin March 2, 2010, and covered the remediation campaign ongoing at the time of this accident. A review of the Safe Work Permit disclosed that the F Area Shift Operations Manager authorized TRU remediation work for one month durations. The AHA analyzed hazards and controls for Procedure 221-F-55006, *TRU Drum Repackaging*, with subtasks covering other remedation-associated procedures.

The Board discovered that AHA FCA-4160, Rev. 4, was approved for use without any required Subject Matter Expert (SME) review or approvals. Investigation by SRNS revealed that a computer software inadequacy permitted finalization of the document after the application had timed-out. The Board found that 24 other AHAs across the site were also approved without required SME review and approval due to this software inadequacy. The AHA addressed "sharps" in general. However, the hazards identified in the AHA were not effectively dispositioned in the specific procedure developed for the remediation work.

On March 18, 2010, Procedure 221-F-55006 was revised (Revision 31), incorporating direction to "Place hole indicator into cans" to demonstrate that the container had been punctured. The procedure provided no explicit direction on the method of installation to be used and did not provide guidance on hazards associated with the use of the survey flag as the hole indicating device, with respect to personnel or potential damage to the Enclosure sleeving. Puncturing the can was viewed as a critical process with appropriate controls, but insertion of the hole indicating device into the punctured container was not viewed as critical and did not have hazards and controls identified.

Several different types of hole indicating devices were used by personnel during the TRU waste remediation work. The Technicians initially used nylon wire tie, but management presumed that the nylon could not be identified by RTR and the WRTs began using stranded wire. The ends of the stranded wire were later recognized as sharps by workers and use of the wire was replaced with survey flags (Figure 3-1). The Board found that no formal hazards analysis had been conducted for use of any of these hole indicating devices prior to their introduction into the Enclosure. When the survey flag was selected as the hole indicating device on April 7, 2010, project management informally reviewed the use of the flag and considered its hazards and associated controls to be "bounded" by the existing AHA. However, using "bounding conditions" is not recognized by SRNS Manual 8Q Procedure 122, *Hazard Analysis*, as a method of adequately analyzing hazards and identifying appropriate controls for performing work.

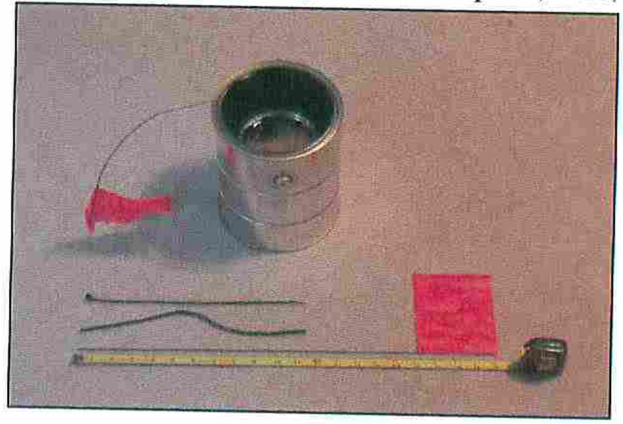

Figure 3-1. Hole Indicating Devices

The Technicians were informally trained (via demonstration) to hold the survey flag at the midpoint with their hands, insert the flag downward into the can, and bend it over at the top of the can (Figure 3-2). However, the Board found that at least five alternative methods of installing the flag were performed by Technicians without analysis of the hazards. Various methods were developed by the Technicians to ensure the flags did not fall out of the cans and could be identified during subsequent RTR.

In addition to the use of different methods of installation, the Board found that survey flags were modified (i.e., cut) by personnel in the field without an understanding of the potential hazards presented by this action. The flags were cut to reduce the height of the flag protruding from the can. As manufactured, the survey flags measure 20-¾ inches in length.

SRNS Employee Safety Manual 8Q, Procedure 51 states, "Documented Final Acceptance Inspections (FAI's) are required before new or altered equipment is placed in service…". The procedure requires the Custodian, Facility Administrator, or Facility Manager to jointly determine, in conjunction with the area safety engineer, whether an FAI is required before new or altered equipment is placed in service. The Board found that no

Figure 3-2. Method of Inserting Survey Flag as Hole Indicating Device

FAIs had been performed for the survey flag or for any of the existing modified extension tools that were introduced into the Enclosure, and found no evidence that a deliberate decision was made whether or not to perform these inspections.

When the TRU waste campaign transitioned to remediation of sealed cans containing waste, the Board discovered that cans were being vented with tools available within the Enclosure, such as a hammer-like chisel. Procedure 221-F-55006 simply stated to open these cans; it contained no precise instructions on how to open them. Additionally, no hazard analysis was performed on this method of venting the cans. Following initial attempts to vent the cans with hand tools, remediation activities were suspended due to potential injury concerns raised by workers. In response, a Safety Significant can puncture device was designed and built for venting subsequent cans. Although workers appropriately raised safety concerns with venting cans with hand tools, the Board determined that management's initial approach to this phase of work was inadequate; management allowed the wrong tool to be used for the job, did not ensure an adequate procedure was in place, and did not ensure a specific hazard analysis had been performed.

Hazards analysis is also conducted through the SRNS Manual 4Q, *Industrial Hygiene Manual*, to identify and control occupational exposure to chemical, physical, and non-ionizing radiation hazards. Regulatory compliance with DOE Orders and DOE-prescribed occupational safety and health standards is achieved using the hazard prevention and control measures described in 4Q Procedure 105, *Hazard Prevention and Control*, Rev. 7. The Board found that an industrial hygiene hazard analysis (Work Force Hazard Characterization Document IH-2006-01517) had been conducted during earlier phases of the TRU remediation work, but had not been updated to address the current work scope and conditions. For example, the hazard characterization did not recognize the use of a sawzall to cut the bolt on the lid of the 30-gallon waste drum that is performed under the current workscope. The document did prescribe specific PPE, including gloves, to be worn during completion of the remediation workscope.

The Work Force Hazard Characterization Document and the Safety and Health Program (HASP) for TRU Waste Operations identified the following chemicals that may be encountered from the waste: methylene chloride, lead, mercury, 1-1-1 trichloroethane, acetone, xylene, benzene, methyl alcohol, beryllium, hydrofluoric acid (hydrogen fluoride), cadmium, and toluene. However, the Board found that chemical compatibility evaluations for the proper selection of PPE and other items introduced into the Enclosure were not performed.

The Board concluded that hazards associated with TRU waste remediation activities were not adequately identified and analyzed.

3.4 Develop and Implement Hazard Controls

The objective of developing and implementing hazard controls is to identify and provide all engineering, administrative, and personal protective equipment requirements consistent with the hazards to be encountered. To adequately develop and implement hazard controls, the work scope must first be well defined and the hazards thoroughly analyzed. For this accident, the failure to adequately define the scope of work and then the failure to properly develop and analyze the hazards precluded the development and implementation of effective hazard controls.

Section 4.1 of the Procedure 221-F-55006, "Precautions and Limitations," contains a general warning that: "Sharps may be encountered during remediation activities. Tools shall be utilized when handling broken glass pieces, razor blades, needles, metal shavings, nails/drill bits, screws, etc. When handling jagged metal/tools, wire, welding rods, wood pieces (splintered), and glass pipettes use tools when possible. Exercise extreme caution when handling sharp items. Sharps shall be padded or covered prior to placing in Parent or Daughter Drums. Cut-resistant gloves shall be worn while sorting waste." The Board noted that the procedure did not specifically identify the survey flags as sharps. The Board also noted that while the AHA identifies Kevlar and cut-resistant gloves as appropriate controls for Non-Radiological Personal Protective Equipment for this job, their use was not defined in the procedure. Workers were taught in radiological containment training to wear Kevlar gloves on the opposite hand when cutting with box knives. However, the Board found that Kevlar gloves were never used inside the Enclosure. Hyflex (cut resistant) gloves were initially required to be worn at all times under the enclosure gloves at the start of the TRU Repackaging evolution in 2006. However, the use of these gloves was later discontinued, without formal documentation, because the workers experienced dexterity problems. Lineman's leather gloves, which are not tested or rated for cut protection, were used in the Enclosure for protection against sharps. Through interviews, the Board disclosed that because leather gloves were considered to be effective PPE for the work, workers expected the gloves to protect them from all hazards encountered.

Work Force Hazard Characterization Document IH-2006-01517, applicable to the TRU remediation workscope, specifies that PPE include the following gloves: two pair of surgical gloves, one pair of anti-cut Hyflex gloves; one pair of yellow anti-contamination gloves, one pair of 31 mil glovebox gloves, and one pair of lineman's gloves. Referenced in IH-2006-01517 is a white paper, "Removal of Containerized Liquids From TRU Waste in 773-A (U)." This paper states, "The chemical remediation process requires the employees to manipulate the containerized liquids through 35 mil neoprene glove box gloves. While handling chemicals an extra pair of 15 mil nitrile gloves will be worn over the glovebox glove to prevent prolonged contact between chemicals inside the glove box and the protective gloves." The Board found that for the work ongoing at the time of the accident, the Technicians were not wearing anti-cut Hyflex gloves, Kevlar gloves, nitrile gloves, or yellow anti-contamination gloves. Additionally, the enclosure gloves being used were only 20 mil vice the 31 mil specified in the Work Force Hazard Characterization or the greater 35 mil specified in the associated white paper. The Board also found that no formal safety review was conducted on the use of Hyflex gloves and the Personal Protective Equipment Oversight Committee was not requested to test or evaluate the gloves prior to use.

Procedure 221-F-55013, *Replacing TRU Repackaging Enclosure Gloves*, Rev. 8, provides no specifications for replacement gloves. The procedure states that personnel should ensure that a "new, inspected enclosure glove" is available for installation. Attachment 1 requires the Technician to record only the glove number and manufacture date. No guidance is provided to determine whether the glove was inspected and the procedure does not specify the manufacturer's name, brand, or thickness.

Engineered controls were not identified and put in place for inserting the survey flag into the punctured can. Use of hand tools was not specified for this activity, allowing direct handling of sharps using gloved hands. In the case of this accident, the Technician's hands were in contact with the sharp end of the survey flag during placement of the flag into the punctured can. Through interviews, the Board found that Technicians stated they were aware that the survey flag was a sharp, but were concerned only with the potential for the flag to puncture the Enclosure's bag-out sleeving; the workers did not consider the device to be a personal hazard that could penetrate their PPE.

During the accident investigation, the Board requested that an independent review of the hazards and controls associated with the Enclosure be conducted by the DOE-SR Assistant Manager for Nuclear Materials Stabilization Project, Nuclear Materials Engineering Division. Discrepancies were identified that indicate further review of the Enclosure design requirement, the crediting of controls identified in the Consolidated Hazard Analysis Process, and the controls brought forward in the Documented Safety Analysis and Technical Safety Requirements is necessary. The review also identified conflicting assumptions and methodologies between radiation protection and accident analysis reviewers in the Consolidated Hazards Analysis Process related to dose calculations and their use in the hazards analysis (OFI).

The Board also evaluated WCMA ventilation controls as part of the investigation and found that administrative controls had been instituted on the "security" door during entry into WCMA. The controls were put in place as a result of an increase in air flow turbulence which had caused a spread of contamination (months prior to the accident) at the opened end (drum dumper area) of the Enclosure. The turbulence resulted from the shutdown of the Canyon Supply Fans during deactivation work. The corrective action implemented by the facility was to administratively control the opening of the "security" door by relocating personnel from the opened end of the Enclosure when the security door is opened. This administrative control prevents workers from immediately becoming contaminated or exposed to an increase in airborne radioactivity, but does not prevent contamination from being released from the open Enclosure into the work area. As a result, the Board determined that an evaluation of more robust control(s) is warranted, especially as the facility moves towards processing higher Pu-238 activity drums (OFI).

The Board concluded that management failed to ensure the development and implementation of adequate controls to protect workers during the TRU waste remediation process.

3.5 Perform Work within Controls

The five ISMS Core Functions are designed to ensure that safety is effectively considered and implemented during all phases of work activities. The failure of any one of the core functions will result in the failure to effectively accomplish subsequent core functions. If the specific work scope to be accomplished is not clearly identified, or if work scope changes are not recognized, the task-specific hazards associated with the specific work scope cannot be properly identified, and controls cannot be put in place to protect employees when work is performed.

On June 14, 2010. at 1135 hours, WRT-1 was working in the Enclosure and reported that his hand had been punctured while attempting to install a survey flag into the quart-sized can. Work was suspended and the RPI responded to aid the injured WRT. WRT-1 was successfully removed from the work area without the spread of contamination or any increase of airborne radioactivity levels. A subsequent survey of WRT-1's outer anti-contamination gloves revealed 1000 dpm/100 cm^2 alpha and no detectable beta-gamma contamination. A survey of the wound on the right index finger indicated 300 dpm alpha. WRT-1 was transported to the Site Medical facility to attempt to decontaminate the wound.

The Board's investigation revealed that WRT-1 was not wearing all the PPE prescribed in the Radiological Work Permit. WRT-1 was only wearing two pairs of the surgical gloves, when three pairs were required. The Board found that WRT-1 had developed an alternate technique for installing the survey flag into remediated TRU cans. WRT-1 bent the survey flag approximately 180 degrees into a "U" shape with the flag's cut end (sharp) pointing upwards. On the day of the accident, WRT-1 had grasped the survey flag in a manner such that the cut end was pointing towards his fingers. As WRT-1 attempted to insert the flag, an obstruction in the can was encountered. At this time, the force applied to the end of the flag overcame the resistance of the leather lineman's glove, as well as the enclosure glove and all other anti-contamination gloves, and penetrated WRT-1's hand at the base of the right index finger. WRT-1's modified method of survey flag installation was not noticed by his co-workers in the Enclosure or by personnel observing work at the video control station (including the procedure reader, firewatch, First Line Managers, and Conduct of Operations mentors).

Through interviews and observation of video footage of waste remediation operations in the Enclosure, the Board discovered that WRTs had developed at least five different methods of installing the survey flags. WRTs stated that the survey flags needed to be installed so they would not fall out of the punctured can, because re-remediation of the drum would be required if subsequent RTR could not identify the survey flag installed though the vented hole. The Board found that workers had not brought their concerns about flag installation to the attention of management in pre- or post-job reviews prior to the accident. The installation methods developed by Technicians were not in accordance with the method demonstrated by management. These deviations from the demonstrated method were not identified and corrected by management. First Line Managers and peer workers observing work evolutions at the video control station failed to note that WRTs had developed numerous methods of manipulating the flags to keep them from falling out of the cans.

Through interviews, the Board also learned that after initial use of the wire survey flags, personnel were shortening (cutting) the flag's wires in another attempt to keep them from falling out of the cans. Wire survey flags as received from the manufacturer are 20-¾ inches long. A short period of time after shortened flags were being used, a worker noted that when the flags were cut, a sharp end was produced. Interviews conducted by the Board revealed that supervision believed the practice of shortening the flags had been curtailed at the time the worker identified the sharp issue. However, during entry into the Enclosure workspace to examine the evidence after the accident, the Board discovered that the wire survey flag used by WRT-1 had been shortened. Subsequent examination of this flag in the laboratory determined that the flag was 16-5/8 inches long and had been cut, leaving a sharp tip. Although supervision believed that the practice of cutting flags had been stopped, shortened survey flags were still being used at the time of the accident. Cutting of the survey flags was done without proper analysis or approval of management, and their continued use went unnoticed by supervision.

The Board found that use of wire survey flags as hole indicating devices was incorrectly perceived by management and workers as a non-hazardous evolution, particularly in comparison to puncturing potentially pressurized TRU waste cans. The Operations Manager conducted demonstrations of the proper technique for survey flag installation at pre-job briefings held between April 16, 2010, and April 23, 2010. The method demonstrated was to hold the flag in the center, simply insert the flag bottom into a can, and bend the flag over. The Board noted that the demonstration was on a large (one-gallon) can, and no additional demonstration was provided on smaller cans. The small cans contained various waste items (obstructions within the can), while the one-gallon cans contained more free space allowing flags to be more easily inserted. The demonstration of survey flag installation into the one-gallon can was not representative of the actions required to place a survey flag into a quart-sized can that may be full of solids.

The Board concluded that an opportunity was missed to effectively use a "Time Out" to address issues related to survey flag installation and receive formal disposition (including a proper hazards review) prior to developing new methods of installation and shortening the survey flags.

There are two video cameras installed within the Enclosure and an additional camera targeting the WCMA outboard of the Enclosure. Camera images are projected on video screens at the Control Station in the WCMA Radiological Buffer Area. The camera located at the bag out port end of the Enclosure is the only camera feed that can be recorded and is the camera normally controlled by the procedure reader during work evolutions. The view from the camera at the drum tilt end of the Enclosure is blocked whenever a drum is tilted up for unloading. When the use of survey flags began on April 23, 2010, installation of the flags into the cans was performed by one WRT. For efficiency purposes, installation of the survey flags evolved to installation of flags into cans by three WRTs working in parallel. The arrangement of the cameras does not allow simultaneous observation of all three work stations in the Enclosure. The Board found that during remediation work, after the can puncture evolution was completed, the camera was typically targeted at the tray-in-pan arrangement to observe cleaning of the tray. The Board determined that installation of the survey flags was not considered a critical step or a hazardous activity by management, and the activity was therefore not necessarily observed or recorded on the video. During the contractor's root cause analysis performed after the accident, SRNS self-identified an action to install additional cameras and monitoring equipment to provide the capability to monitor all processing positions simultaneously. However, SRNS did not consider this corrective action to be required to be complete prior to resumption of remediation activities. The Board determined that installation of the necessary cameras to enable monitoring of all WRT work activity in the Enclosure should be completed prior to resumption of evolutions involving simultaneous work at multiple stations (OFI).

The Board concluded that management did not consider installation of the survey flags a critical step or a hazardous activity, and the activity was therefore not necessarily observed or recorded on video.

Management and Supervisory Oversight

First Line Managers for TRU waste remediation in F Area were selected for these positions from a pool of experienced personnel from the 2006–2008 TRU waste remediation campaign. These experienced personnel were promoted to "detailed" First Line Managers, which are temporary promotions for the duration of the ARRA campaign. These managers entered the ARA/HCA/RA at the start of the ARRA TRU waste campaign and performed technician duties until the Technicians became oriented to this phase of the work. After that time, no further entries were made by First Line Managers into the ARA/HCA/RA to observe work. The Board also found that other management, industrial hygiene, safety personnel, mentors, self-assessment teams, and the Facility Evaluation Board never entered the ARA/HCA/RA. Instead, they observed operations from the Radiological Buffer Area via video screens. Cramped quarters were typically the rationale for personnel not entering the ARA/HCA/RA. However, this approach did not afford an appreciation of the poor working conditions of the Enclosure workspace and surrounding areas.

A Conduct of Operations Mentor Program was in place at the time of the accident, governed by a program document, *ARRA ConOps Mentor Program*, dated September 1, 2009. The intent of the Mentor Program was to provide additional defense-in-depth to ensure ARRA work was performed safely. Mentors were assigned with the work crews to help them maintain the appropriate rigor in the implementation of work. They gave no direction to the work crew unless an imminent safety situation required action. Mentors maintained a log of positive and negative observations of F-TRU work. A Board review of the mentor log revealed that mentors regularly identified issues requiring resolution on shift and also identified positive attributes of the work. The logs were maintained electronically and observations were de-briefed to upper project management personnel on a regular basis (nominally monthly). This log was not widely distributed. The Mentor Program was not designed for mentor issues to be tracked in the company's deficiency database. As a result, issues identified by the mentors were not formally tracked to closure. Additionally, no formal performance indicators were established to enable tracking, trending, or forecasting of performance (OFI).

Throughout the F-TRU waste remediation campaigns, management observers (including project managers, mentors, and personnel standing Senior Supervisory Watch) repeatedly observed workers challenging sharps. For example, workers were chronically cited for not wearing outer protective gloves, such as lineman's or HexArmor® Over Glove (HOG) gloves, for holding items to be cut with their hands rather than using a grasping tool, and for pushing waste with their hands instead of using a pushing tool. These chronic issues were addressed for each individual case, but were not institutionally resolved by management.

The Board concluded that management did not establish appropriate expectations for disciplined conduct of work, did not institutionalize meaningful corrective actions for significant issues, and did not effectively oversee the performance of work.

The Board concluded that management and other contractor oversight groups missed the opportunity to improve working conditions and ensure compliance with expectations by not entering the workspace and observing work first hand.

Conduct of Operations

On July 27, 2010, the Board attended a pre-job briefing for the mock-up training on TRU drum repackaging at the mock-up facility in 766-H in accordance with Procedure 221-F-55006. Detailed discussions on the hazards, controls, and emergency responses were held with the workforce. At the mock-up, all preliminary work instructions in the procedure were deliberately executed. During removal of the 30-gallon drum lid, which was taped in place, workers attempted to remove tape from the drum using a locally manufactured drum lid prying tool found in the Enclosure that was not intended for this purpose. Several attempts were then made to pry the lid off with various tools including tongs and a hand rake. The two workers struggled during the removal of the lid and became discouraged with each other. The First Line Manager observing the evolution did not take any action to resolve the situation or simply call a time-out. After the lid was removed, one-gallon cans were removed from the 30-gallon drum. The Board observed workers inappropriately using the pointed end of scissors to stab into the plastic wrapping on the cans to begin the cutting process.

The Board concluded that during performance of Procedure 221-F-55006 at the mock-up facility, a less than adequate display of disciplined operations in accordance with SRNS Manual 2S, Conduct of Operations, was demonstrated.

During interviews, the Board noted that prior to the event, pre-job briefings were regularly held prior to each shift; however, supervisors led the majority of the discussions. There was very little employee engagement and feedback. The Conduct of Operations program had not matured to the point of using reverse briefings, where workers describe actions they will be performing during the shift. Post-job reviews were conducted and documented; however, the majority of workers interviewed by the Board could not recall that they had ever taken place. The post-job reviews that were conducted were ineffective in identifying the worker's concerns related to the possibility of the survey flags falling out of the cans.

The Board concluded that pre-and post-job reviews were not fully effective.

3.6 Provide for Feedback and Improvement

Feedback and improvement processes should be designed and implemented to provide information on the adequacy of work controls, to identify and implement opportunities for improving the definition and planning of work, and to utilize line and independent oversight processes to provide information on the status of safety. The feedback and improvement function is intended to identify and correct processes or conditions that lead to unsafe or undesired work outcomes, confirm that desired work outcomes were arrived at in a safe manner, and provide managers and workers with information to improve the quality and safety of subsequent, similar work. The Board reviewed feedback and improvement mechanisms implemented by both DOE and SRNS.

DOE Oversight

On October 30, 2009, a Memorandum of Understanding (MOU) was issued by the DOE-SR Assistant Manager for Nuclear Material Stabilization Project (AMNMSP) and the Assistant Manager for Waste Disposition Project (AMWDP) that described the responsibilities and requirements for safety oversight of ARRA workers performing TRU remediation activities within F Canyon. The MOU was needed as AMWDP program work was to be performed in a facility owned by AMNMSP. The Memorandum of Understanding adequately describes the division of responsibilities between the organizations in the areas of facility ownership, maintenance, Authorization Basis, occurrence reporting, emergency response, work control, radiological controls, monthly contractor feedback, and issues management.

AMNMSP uses an annual assessment plan to schedule assessments for the year. These assessments are documented in the DOE-SR Site Integrated Management Total Assessment System (SIMTAS). Assessments that identify a Concern, Deficiency, Observation, or Good Practice are reviewed by a DOE-SR Management Review Board and forwarded to the appropriate contractor for resolution or for information in the Monthly Assessment Report.

Day-to-day field oversight of TRU remediation activities in F Canyon is provided by Facility Representatives from AMNMSP and an ARRA staff augmentation contracted Field Engineer. Numerous issues have been generated from field oversight of TRU remediation activities in F Canyon by the Facility Representatives and the Field Engineer. These issues were transmitted to SRNS via Monthly Assessment Reports and include items such as:

- Inadequate procedures and less than adequate execution of procedures
- Improper operation of the breathing air compressor
- Administrative procedure change issues
- Donning air fed hoods prior to verification of a critical step
- Less than adequate turnover for radiological control inspectors
- Lack of use of the company's deficiency database (STAR)
- Training inadequacies
- Discovery of a Safety Significant calculation using a non-certified spreadsheet database

On April 29, 2010, approximately six weeks prior to the puncture accident, the Assistant Managers for Waste Disposition Project and Nuclear Material Stabilization Project wrote a joint letter of concern to SRNS regarding recent events involving TRU waste remediation activities conducted in F Canyon. The issues indicated that increased management attention was required in preparation for and performing work, and included the following:

- Ventilation system changes that resulted in less conservative dose assessment calculations and respiratory protection determinations.
- Failure to execute a procedure step which served to implement Authorization Basis requirements.
- Improper use of the container puncture device/shield.
- Potentially pressurized containers were punctured without the required shielding.
- Chronic procedure development issues, including omission of steps implementing Authorization Basis controls.

Contractor feedback meetings were held on a regular basis between SRNS and AMWDP management. Information from TRU remediation operations in F Area were forwarded from AMNMSP to AMWDP as AMNMSP personnel were overseeing day-to-day operations in this area. Relevant assessment results and issues were consistently provided to SRNS management in these reports.

Managers in AMNMSP had performed 385 hours of management walkthroughs for Fiscal Year 2010 compared to a goal of 352 hours. A review of the SIMTAS database for these walkdowns revealed a variety of AMNMSP facilities were visited. Operational activities observed included TRU drum movements, TRU remediation work in F Canyon, TRU remediation mockup evolutions, attendance at shift turnover briefings, and attendance at fact-finding meetings.

The Board concluded that DOE-SR AMNMSP Facility Representatives and management were actively engaged in oversight of TRU waste remediation activities in F Canyon and provided the contractor appropriate and meaningful feedback through Monthly Assessment Reports, monthly contractor feedback meetings, and a DOE letter of concern issued prior to the accident.

DOE Independent Oversight Activities

The Board reviewed the results of three DOE independent assessments conducted between 2007 and 2010 for relevancy and lessons learned with respect to this accident (*SRS EM-60 ISM Program Assessment Report*, January 2007; *SRS EM-62 Assessment Report,* January 2008; *DOE Office of Independent Oversight Inspection of Environment, Safety and Health Programs at SRS*, January 2010). The Board found that deficiencies noted in the previous assessments related to AHAs, radiological protection, and safety basis knowledge still existed and were similar to conditions found related to this accident.

Most recently, the January 2010 assessment conducted by the DOE Office of Independent Oversight found that, "Although SRNS has improved the AHA process since the 2006 inspection, continued weaknesses in institutional processes and insufficient rigor in application of various AHA process requirements have resulted in instances in which hazards were missed or controls were not tailored to the work activity, not adequately specified, or lacked rigorous implementing mechanisms."

The Board concluded that the corrective actions to address previously identified issues involving hazards analysis were not effective in preventing a recurrence of the identified deficiencies.

Contractor Readiness Reviews

Three contractor readiness reviews were completed over the lifecycle of the ARRA F-TRU Drum Remediation project prior to the accident.

- The F-Canyon TRU Drum Remediation Restart Assessment was conducted from September 23, 2009, to October 9, 2009 and self-identified procedure quality issues, issues with worker's usage of procedures, and training packages that were not in accordance with site requirements.

- The F-Canyon TRU Drum Remediation Restart (Independent Assessment) was conducted from October 28, 2009, to November 4, 2009, and self-identified numerous procedure issues, lengthy pre-job briefings with minimal worker input, and inadequate staffing to perform the TRU remediation task without further training and/or implementation of compensatory measures. In response to the staffing issue, a *Management Control Plan for F-Canyon TRU Drum Remediation Operations*, M&O-FCP-2006-00019, Rev. 1 was issued on November 5, 2009. This management control plan included compensatory measures to be implemented such as assembling a core team of workers to begin operations, use of the First Line Manager as a WRT to begin work in the Enclosure, establishment of a Conduct of Operations Mentor Program, working with low plutonium equivalent curie drums to start the campaign, and implementation of Senior Supervisory Watch as necessary.

- The F-Canyon TRU Drum Remediation PHASE II (FAM Assessment) was conducted from February 9, 2010, to March 9, 2010, and self-identified worker and First Line Manager weaknesses in knowledge of the characteristics and hazards of Pu-238. In response, a one-hour briefing was presented March 23, 2010, on the differences between Pu-238 and Pu-239, the contamination concerns of Pu-238, and the need to avoid complacency when working with Pu-238.

The Board's review of corrective actions taken in response to issues identified in these reviews revealed that briefings were commonly used rather than formal training. The conduct of briefings does not provide for sufficient feedback from recipients to ensure that the subject matter is truly understood.

The contractor's ARRA Facility Evaluation Board performed an ISM Evaluation of F Area TRU Waste Remediation from January 6, 2010, to January 15, 2010. The review identified procedure performance weaknesses, such as the lack of tool use to move waste within the remediation Enclosure. This team also identified engineering issues associated with the Unreviewed Safety Question process and weaknesses in the evaluation of procedure, equipment, and design changes against Safety Basis documents.

The Board found that in all four of the contractor readiness assessments, no assessment team members actually entered the remediation Enclosure workspace, which is an ARA/HCA/RA. The opportunity to observe work first-hand, enforce management expectations, and identify generally poor working conditions/housekeeping was missed.

The Board concluded that while the conduct of contractor readiness reviews was adequate, the disposition of issues identified during the reviews was not comprehensive, formal, or long-lasting.

Contractor Assessment Activities

SRNS implements the self-assessment process in accordance with Manual 12Q, *Site Assessment Manual,* Procedure SA-1, *Self-Assessment*. On January 12, 2009, the "Area Completion and Solid Waste Management 2009 Self Assessment Plan" was issued and covered the period from January 5, 2009, through February 28, 2010. On March 10, 2010, the "Fiscal Year 10 ARRA Integrated Self Assessment Plan" was issued. These plans assigned assessors responsibility for covering a wide array of assessment topics, but did not necessarily identify specific areas within the various ARRA projects in which to perform the assessments. In April 2010, the F-TRU Project Manager self-identified that a separate assessment plan was needed for F Area TRU Projects. However, at the time of this report, no separate plan had been issued. Prompt issuance of a specific F-TRU assessment plan would be prudent to better define oversight expectations for F-TRU remediation work (OFI).

The Board reviewed records documenting self assessments and Management Field Observations (MFOs) from July 2009 through June 2010. Self assessments documented during this period for F-TRU repackaging activities included topics such as radiological air sampling and postings, the beryllium program, Quality Assurance, criticality safety, and temporary modifications. In addition to self assessments, MFOs are used to get managers in the field to meet with the workforce, understand the field processes, and to relay management's message on safety directly to the workers. The Board's review of MFOs revealed that management was getting in the field to observe work. Positive attributes were documented, and issues that were identified (such as anti-Contamination doffing techniques, the need to wear leather gloves over the enclosure gloves, and ambient hot/cold working conditions) were either corrected on the spot or entered into the deficiency tracking system (STAR). However, the Board noted that none of the self assessments or MFOs included a recorded observation on the use of the hole indicating device. Additionally, the Board noted that no entries had been made into the Enclosure work area (ARA/HCA/RA) during any of these assessments.

The Board concluded that although an active contractor assessment program existed at the F-TRU waste remediation project, an opportunity was missed to identify hazards associated with the use of a survey flag during remediation activities by not assessing work in the actual work location.

Previous Occurrences and Lesson Learned

The Board reviewed nine similar Occurrence Reporting and Processing System (ORPS) reports/lessons learned from SRS and Los Alamos National Laboratory to determine whether the corrective actions were incorporated in the F Canyon TRU work (NA-LASO-LANL-CMR-2007-0002; NA-LASO-LANL-TA55-2008-0016; NA-LASO-LANL-TA55-2008-0019; EM-SR-WSRC-HBLINE-1993-0037; EM-SR-WSRC-HBLINE-1994-0001; EM-SR-WSRC-FGEN-1995-0055; EM-SR-WSRC-HCAN-2001-0002; EM-SR-WSRC-ALABS-2006-0004; and EM-SR-WSRC-ALABS-2006-0006).

In 2006, F/H Laboratory in F Area was conducting similar TRU waste repackaging activities and the workers were wearing similar PPE to that required for the F Canyon TRU work. Two separate events involving hand puncture wounds were experienced during the waste handling operations in 2006. Corrective actions were identified but not all were implemented because the laboratory elected to discontinue waste repackaging following the second puncture event. The current TRU waste remediation team reviewed and implemented some of the corrective actions from these events (e.g., long-reach tools and waste compression tool).

At Los Alamos (NA-LASO-LANL-TA55-2008-0019), a worker received a puncture from a metal shaving. Leather overgloves had been previous identified as required PPE to reduce the possibility of punctures. As a result of the use of the leather overgloves, the technicians felt fairly "safe" and were surprised that a leather glove, glovebox glove and anti-contamination gloves were actually penetrated. For the June 14, 2010, accident at SRS, the Technicians involved in the F-TRU work had the same perception that leather gloves provided adequate protection from the tip of the survey flag.

After evaluating the nine events, the Board determined that most of the accidents were caused by the inappropriate handling of tools and improper selection of PPE for the task. Common corrective actions for the nine events included the following for tools and PPE:

Tool corrective actions:

- Inspection of process cabinets to identify and remove sharp objects, tools, wire, etc.
- Proper taping of sharp edges on tools and rodding wire.
- Assurance that sharp tools were appropriate for the job and used as intended in a safe manner.
- Ensuring that sharp tool use was approved by a work authorization document.

PPE corrective actions:

- Recommend the use of puncture-resistant gloves.
- Provide guidance, to include nitrile puncture-resistant gloves, for work around sharps and handling waste with sharp edges.

The Board found that for the F Canyon ARRA TRU work, nitrile gloves were not used; tools with sharps were not properly analyzed; Technicians were observed in the mock-up using the wrong tools for the job; and sharp tools were not properly protected.

The Board concluded that not all corrective actions related to TRU repackaging and handling sharps were properly incorporated into the F Canyon TRU work. While several engineering controls were in place for the TRU remediation and repackaging process, many steps in the process were still done by hand.

The Board concluded that the process for evaluating and implementing ORPS corrective actions and lessons learned was not fully effective.

3.7 Personnel Training and Qualifications

ISM Guiding Principle 3, "Competence Commensurate with Responsibilities", means that personnel are expected to possess the experience, knowledge, skills, and abilities necessary to discharge their responsibilities. The Board evaluated the training and qualifications for personnel involved in the ARRA F-TRU drum remediation work scope. The following was noted:

- SRNS Manual 4B, *Training and Qualification Program Manual*, Procedure 4.0, *Qualification and Certification Programs*, Rev. 3, differentiates between "operators" and "technicians" and allows for a graded approach to be applied. Operator training and qualification must be sufficiently comprehensive to cover areas fundamental to the assigned tasks. The procedure states that facility operator training shall include (1) a core of subjects such as industrial safety, instrumentation and control, basic physics, chemistry, industry operating experience, and major facility systems as applicable to the position and the facility; and (2) classroom and on-the-job training to include normal and emergency procedures, administrative procedures, radiation control practices, location and functions of pertinent safety systems and equipment, procedures for making changes or alterations in operations and operating procedures, and technical safety requirements. In contrast, Section 4.A states that Technicians shall be qualified to perform the tasks associated with their specialty, or work under the direct supervision of personnel qualified to perform the activity or task. Technician training shall include (1) demonstrated performance capabilities to ascertain their ability to adequately perform assigned tasks, and (2) training on safety-related systems identified in the facility Safety Analysis Report to include system training on the following elements: purpose of the system; general description of the system including major components, relationships to other systems, and all safety implications associated with working on the system; and related industry and facility-specific experience. The procedure defines Technicians as personnel who are principally involved in calibration, inspection, troubleshooting, testing, maintenance and radiation protection activities.

  The Board found that management made a decision to identify the remediation workers as Technicians rather than Operators. This decision allowed the training provided to the Technicians to be focused on the specific tasks that management determined each group would be performing instead of a series of responsibilities that the worker might be expected to perform if they were classified as an Operator. As a result, the training provided to the Technicians did not provide the workers with an in-depth knowledge of procedures, safety implications, system knowledge, and technical safety requirements, including a complete understanding of plutonium hazards. The Board found that briefings were used to provide training on important operational information (including plutonium hazards). SRNS Manual 4B, *Training and Qualification Program Manual*, defines a briefing as a "formal, documented presentation to employees for the purpose of receiving information related to the conduct of job duties or tasks considered a viable option for certain *low* [emphasis added] hazard tasks and/or functions.

Procedure PROGQRPOPDES000114, *Radiological Protection Department, Training and Qualification Program Description*, dated June 2010, states in Figure 1 of Section 6.6.2 that the training period for a Radiological Protection Inspector (RPI) is 24 months. Section 6.12.1, *Subcontractor Entry Qualifications*, states that subcontractor personnel shall have 3 years prior experience as a Radiological Protection Technician/Inspector to perform RPI duties. The procedure further states that resumes should be reviewed to identify personnel with experience in jobs similar to those for which they will be employed. During interviews, the Board found that all of the subcontract RPIs interviewed stated they did not have previous experience with Pu-238 or with the handing of TRU waste. Through interviews, the Board determined that the training period for subcontract RPIs was shortened from the time period required for a direct hire employee serving as an RPI, which is permitted provided the RPIs have knowledge based on assigned tasks. While the prior work experience of the subcontract RPIs provided a base knowledge regarding routine radiological control work activities, it did not provide them with an appreciation of the specific hazards associated with the F Canyon remediation work. The Board determined that the RPIs' lack of knowledge related to the hazards associated with the work scope resulted in missed opportunities to identify and address accident precursors (OFI).

The Board determined that because the waste remediation workers were classified as Technicians, they did not receive the same level of knowledge and skill training as Operators.

- Prior to the accident, on March 23, 2010, workers were provided with a briefing on Pu-238. No examination was administered to ensure the target audience understood the material. During interviews, the Board found that personnel exhibited a general lack of knowledge of the hazards associated with work involving Pu-238. Additionally, a review of the Class Implementation Record associated with the briefing disclosed that the briefing was not provided to all workers (two Radiological Protection Inspectors were among the personnel not trained). The Board also found that attendance at the briefing was not recorded in the SRS training history database for any of the individuals listed on the Class Implementation Record. The Board determined that the training was not provided to all personnel working with TRU waste drums, and was not sufficient to provide the workers with an adequate understanding of the hazards they would be exposed to during the conduct of TRU waste remediation work.
- The Qualification Cards for workers handling TRU waste drums do not require F Canyon Phase IIA 2009 Safety Basis Documents Revision Training (ZFACTD00). A review of the SRS training history database for selected personnel found that the training had been administered; however, the current Qualification Card does not identify this training as a requirement for continued qualification.
- Detailed First Line Managers were not provided the same suite of training courses that are normally provided to persons being promoted to this position. The individuals were provided leadership training; however, Manual 4B, Procedure 4.0, Rev. 3 in Section 4C requires personnel serving as supervisors to complete the Supervisory Skills Training. This training includes training on leadership, interpersonal communication, responsibilities and authority, motivation of personnel, problem analysis and decision making, fitness for duty procedures, and administrative policies and procedures.
- On at least two occasions (use of the hole puncture device and use of the survey flag as the hole indicating device), the Training organization was not notified of a change in the

work process. On at least two other occasions, Operations personnel provided informal, ad hoc training to workers on crucial process steps using the "mock-up" enclosure located in 766-H and/or demonstrations in pre-job briefings. However, no training objectives, lesson plans or training records were developed for this ad hoc training. The Board determined that the lack of formal training resulted in a missed opportunity to conduct a formal hazards analysis of the work process, tools, and equipment which could have identified the use of the survey flag as the hole indicating device as a sharp.

- A review of several procedure approval sheets disclosed the Training organization is not routinely required to review or approve procedure changes. DOE Order 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Facilities*, requires that procedure or operational changes be reviewed to determine if existing training is sufficient. The Order further states that continuing training must incorporate facility changes to correct identified performance problems and ensure worker safety. SRNS Manual 4B, *Training and Qualification*, Procedure 4.0, Rev. 3, states that continuing training shall include applicable procedure changes and other training as needed to correct identified performance problems. SRNS Manual 2S, *Conduct of Operations,* Procedure 1.1, states that the procedure owner must determine whether the requested procedure change will affect training. The Training organizations' lack of involvement in F-TRU waste remediation work procedure revisions increased the likelihood that formal training did not match conditions in the field and could increase the opportunity for procedure violations.

- A review of training records disclosed that persons assigned as Senior Supervisory Watch (SSW) did not receive a qualification briefing, nor were expectations for this activity established by the Area Project Manager in accordance with SRNS Manual 2S, *Conduct of Operations*, Procedure 5.1, Rev. 6. The procedure also recommends the use of an SSW evaluation sheet to determine whether an individual is suitable for the SSW assignment. The procedure also states that the "Person-in-Charge" (PIC) should be selected based on their knowledge, skill and experience. The Board found that the selection process used for SSWs and PICs for the TRU Waste Remediation Project was not as rigorous as other established programs at SRS. The Board determined that the selection process and lack of clear expectations for the SSW and PIC positions resulted in missed opportunities for these individuals to identify and address accident precursors (OFI).

- The Qualification Cards for Radiological Protection Inspectors and for waste drum handlers did not require completion of F-TRU Waste Remediation Hazards Awareness Training (ZFAIXB01). This classroom training provides workers with an understanding of the hazards associated with Pu-238 and should be required for all workers whose tasks may involve work with this material (OFI).

- DOE-SR Nuclear Materials Operations Division (NMOD) personnel found that the training and qualification program for TRU Waste Remediation personnel does not meet the intent of DOE O 426.2, *Personnel Selection, Qualification, and Training Requirements for Nuclear Facilities*". NMOD determined that the TRU Waste Remediation Training Department did not develop learning objectives to reflect task performance. As a result, required knowledge and skills were not being trained or evaluated. Briefings provided to workers were specific to the qualification area but did not contain any knowledge objectives. Because knowledge objectives were not identified, there was no objective method to determine whether the trainees had the required knowledge to be considered qualified. NMOD also identified that operators detailed as First Line Managers and Process Subject Matter Experts were not required to achieve additional performance demonstrations. (The tracking and closure of this deficiency will be handled outside this accident investigation by NMOD.)

The Board concluded that training and qualifications for personnel associated with the F Area TRU waste remediation work did not ensure that workers had the knowledge, skills and abilities commensurate with their responsibilities. Furthermore, the training provided was not sufficient to provide workers with an adequate understanding of the hazards they would encounter during the performance of the workscope.

The Board concluded that facility management's lack of engagement of the Training organization in the review of procedure revisions resulted in missed opportunities for the development of formal training for new hazards and controls associated with TRU waste remediation work.

3.8 Summary of Analytical Methods and Results

Barrier Analysis

Barrier Analysis is based on the premise that hazards are associated with all tasks. A barrier is any management or physical means used to control, prevent, or impede the hazard from reaching the target (i.e., persons or objects that a hazard may damage, injure or harm). Appendix B contains the Board's Barrier Analysis of the physical and management barriers that did not perform as intended and thereby contributed to the accident. The results of the barrier analysis were integrated into the Events and Causal Factors Analysis to support the development of causal factors.

Change Analysis

Change analysis examines planned or unplanned changes that cause undesirable results related to the accident. This process analyzes the difference between what is normal, or expected, and what actually occurred before the accident. Appendix C contains the Board's Change Analysis. The results of the Change Analysis are integrated into the Events and Causal Factors to support the development of causal factors.

Events and Causal Factors Analysis

An Events and Causal Factors Analysis was performed following the processes described in the DOE Workbook *Conducting Accident Investigations,* Revision 2. The Events and Causal Factors Analysis is a systematic process that uses deductive reasoning to determine which events and/or conditions contributed to the accident. Causal Factors are significant events and conditions that produced or contributed to the accident and include direct, contributing, and root causes. The direct cause is the immediate event or condition that caused the accident. Root causes are causal factors that, if corrected, would prevent recurrence of the same or similar accidents. Contributing causes are events or conditions that collectively with other causes increased the likelihood of the accident, but that individually did not cause the accident. The Events and Causal Factors Table is included as Appendix D.

- The **direct cause** of the June 14, 2010, accident is that a contaminated survey flag punctured the worker's PPE and hand, resulting in a radiological intake.
- The **root cause** was a less than adequate graded approach used for high hazard TRU waste remediation work; this did not coincide with the discipline warranted for high hazard work.

- **Contributing causes** were identified as follows:
  - Management did not follow established protocols to ensure that Subject Matter Experts were involved in the identification and analysis of hazards.
  - Management did not ensure that a formal hazard analysis was conducted for use of the hole indicating devices.
  - The procedure did not identify a method for hole indicating device installation.
  - Formal training was not provided on survey flag installation. Management demonstrated survey flag installation for one-gallon cans but did not provide additional training on one-quart cans.
  - WRTs did not follow the demonstrated method of installing survey flags and did not notify management of their concerns that the survey flag would fall out of the one-quart cans.
  - Management was unaware that alternate, unapproved methods of installing survey flags were being used.
  - WRTs did not understand the safety significance of modifying prescribed equipment and not following survey flag installation as demonstrated.
  - Management did not reinforce to workers the importance of disciplined operations, including use of time-outs and the need to discuss issues during pre- and post-job briefings.
  - Known accident precursors were not adequately dispositioned and continued to exist in the workplace.

4.0 CONCLUSIONS AND JUDGMENTS OF NEED

Judgments of Need are managerial controls and safety measures believed necessary to prevent or minimize the probability of a recurrence. They flow from the conditions and are designed to guide managers in developing effective corrective actions. The Board's Conclusions and Judgments of Need are provided below in Table 4-1. Additional opportunities for improvement are documented in Appendix E.

Table 4-1: Conclusions and Judgments of Need

Conclusions	Judgments of Need
The overall emergency response and the treatment actions provided during this accident were adequate. (Section 2.3)	N/A
Initial radiological protection survey techniques were not in compliance with SRNS Manual 5Q, *Radiological Control*, and the patient was not informed of proper contamination control techniques associated with collection of bioassay voids. (Section 2.3)	JON-1: SRNS needs to reinforce compliance with established procedures for personnel survey techniques following an accident. JON-2: SRNS needs to revise and implement protocols for patient instructions associated with chelation.

Conclusions	Judgments of Need
SRNS's reluctance to share the dose projections from the initial intake impacted DOE's ability to categorize this event in a timely manner based on dose. (Section 2.4)	JON-3: DOE-SR needs to provide clear direction to its contractors to ensure that initial dose estimates are provided as soon as possible following notification of a personnel intake.
DOE-SR failed to ensure that the contractor maintained adequate control of the accident scene prior to arrival of the Accident Investigation Board as required by procedure. (Section 2.5)	JON-4: DOE-SR needs to ensure that accident scenes are preserved in accordance with established procedures and formally turned over to the Accident Investigation Board upon arrival.
SRNS did not preserve and control the accident scene prior to turnover to the Board in accordance with DOE O 225.1A and SRNS procedures. (Section 2.5)	JON-5: SRNS needs to ensure that accident scenes are preserved in accordance with established procedures and formally turned over to the Accident Investigation Board upon arrival.
The commitment to comply with ISMS and regulatory requirements was adequately captured in contract documents and site-level procedures. (Section 3.1)	N/A
The scope of work for the remediation and repackaging work was not fully defined, and the methods used to ensure the development of procedures compliant with SRNS Manual 2S, *Conduct of Operations*, had not matured. (Section 3.2)	JON-6: SRNS needs to improve the rigor of the methods used to ensure quality procedures.
Hazards associated with TRU waste remediation activities were not adequately identified and analyzed. (Section 3.3) Management failed to ensure the development and implementation of adequate controls to protect workers during the TRU waste remediation process. (Section 3.4)	JON-7: SRNS needs to ensure that hazards and controls are identified and properly incorporated into technical work documents.
	(continued)

Conclusions	Judgments of Need
WRT-1 was not wearing all of the prescribed PPE required by the RWP. (Section 2.6) Management and other contractor oversight groups missed the opportunity to improve working conditions and ensure compliance with expectations by not entering the workspace and observing work first hand. (Section 3.5) Management did not establish appropriate expectations for disciplined conduct of work, did not institutionalize meaningful corrective actions for significant issues, and did not effectively oversee the performance of work. (Section 3.5) The corrective actions taken to address previously identified issues involving hazards analysis were not effective in preventing a recurrence of the identified deficiencies. (Section 3.6) While the conduct of contractor readiness reviews was adequate, the disposition of issues identified during the reviews was not comprehensive, formal, or long-lasting. (Section 3.6) Although an active contractor assessment program existed at the F-TRU waste remediation project, an opportunity was missed to identify hazards associated with the use of a survey flag during remediation activities by not assessing work in the actual work location. (Section 3.6) The process for evaluating and implementing ORPS corrective actions and lessons learned was not fully effective. (Section 3.6)	JON-8: SRNS needs to ensure that management and supervision enforce the expectation that work is conducted in accordance with procedures, increase the scrutiny of corrective action reviews to ensure adequacy of the corrective actions to prevent recurrence of previously identified deficiencies, and maintain an effective presence at the work site.
During performance of Procedure 221-F-55006 at the mock-up facility, a less than adequate display of disciplined operations in accordance with SRNS Manual 2S, *Conduct of Operations*, was demonstrated. (Section 3.5)	JON-9: SRNS needs to ensure that First Line Managers display leadership and command-and-control at the work site.
A shortened (cut) survey flag allowed the Technician's glove to be punctured more easily than a new survey flag. (Section 2.6) An opportunity was missed to effectively use a "Time Out" to address issues related to survey flag installation and receive formal disposition (including a proper hazards review) prior to developing new methods of installation and shortening the survey flags. (Section 3.5)	JON-10: SRNS needs to reinforce the use of "Time Out" to resolve issues prior to altering work steps or equipment in the field.

Conclusions	Judgments of Need
Management did not consider installation of the survey flags a critical step or a hazardous activity, and the activity was therefore not necessarily observed or recorded on video. (Section 3.5)	JON-11 SRNS needs to ensure that critical (irreversible) steps in procedures are identified so that proper precautions can be taken prior to performance.
Pre-and post-job reviews were not fully effective. (Section 3.5)	JON-12: SRNS needs to improve the effectiveness of pre- and post-job reviews.
DOE-SR AMNMSP Facility Representatives and management were actively engaged in oversight of TRU waste remediation activities in F Canyon and provided the contractor appropriate and meaningful feedback through Monthly Assessment Reports, monthly contractor feedback meetings, and a DOE letter of concern issued prior to the accident. (Section 3.6)	N/A
The Board concluded that not all corrective actions related to TRU repackaging and handling sharps were properly incorporated into the F Canyon TRU work. While several engineering controls were in place for the TRU remediation and repackaging process, many steps in the process were still done by hand. (Section 3.6)	JON-13: SRNS needs to minimize human contact in TRU waste remediation and repackaging work by using engineering controls, and choose a better selection of PPE to protect personnel from potential hazards when engineering controls are determined not to be practical.
Training and qualifications for personnel associated with the F Area TRU waste remediation work did not ensure that personnel had the knowledge, skills and abilities commensurate with their responsibilities. Furthermore, the training was not sufficient to provide workers with an adequate understanding of the hazards they would encounter during the performance of the work. (Section 3.7)	JON-14: SRNS should evaluate the skill mix for the TRU waste remediation work to ensure an appropriate level of experience is used for work involving TRU waste. JON-15: SRNS should ensure that the training program established for personnel involved with TRU waste remediation and repackaging activities complies with Manual 4B. This training should include more detail on hazards and consequences, prior to the restart of remediation and repackaging work.
Facility management's lack of engagement of the Training organization in the review of procedure revisions resulted in missed opportunities for the development of formal training for new hazards and controls associated with TRU waste remediation work. (Section 3.7)	JON-16: SRNS needs to ensure that facility managers involved in TRU remediation work increase the involvement of the Training organization in the review of procedure revisions.

5.0 BOARD SIGNATURES

Signature on File Jeffrey M. Allison, DOE Accident Investigation Board Chairperson U.S. Department of Energy Savannah River Operations Office Director of Special Projects		*September 1, 2010* Date
Signature on File Mark A. Smith Trained Accident Investigator/Analyst U.S. Department of Energy Savannah River Operations Office Nuclear Safety Programs Manager, Office of Safety and Quality Assurance		*September 1, 2010* Date
Signature on File J. J. Hynes U.S. Department of Energy Savannah River Operations Office Supervisor, Assistant Manager for Closure Project		*September 1, 2010* Date
Signature on File David E. Sanders, Jr. U.S. Department of Energy Savannah River Operations Office Facility Representative, Assistant Manager for Closure Project		*September 1, 2010* Date
Signature on File William C. Dennis, Jr. U.S. Department of Energy Savannah River Operations Office Director, Security Programs and Emergency Services Division		*September 1, 2010* Date

6.0 BOARD MEMBERS, ADVISORS, AND STAFF

Board Chair	Jeffrey M. Allison, DOE Accident Investigation Board Chairperson U.S. Department of Energy Savannah River Operations Office Director of Special Projects
Member (Investigator/Analyst)	Mark A. Smith U.S. Department of Energy Savannah River Operations Office Nuclear Safety Program Manager Office of Safety and Quality Assurance
Member (Investigator)	William C. Dennis, Jr. U.S. Department of Energy Savannah River Operations Office Director, Security Programs and Emergency Services Division
Member (Investigator)	J. J. Hynes U.S. Department of Energy Savannah River Operations Office Supervisor, Assistant Manager for Closure Projects
Member (Investigator)	David E. Sanders, Jr. U.S. Department of Energy Savannah River Operations Office Facility Representative, Assistant Manager for Closure Project
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Technical Editor	Lauren Wabbersen National Nuclear Security Administration NA-262 Site Engineering & Project Integration Division

DOE F 1325 8

United States Government **Department of Energy (DOE)**

memorandum

Savannah River Operations Office (SR)

DATE: JUL 2 8 2010

REPLY TO ATTN OF: AMNMSP (C. Everatt, (803) 208-3534)

SUBJECT: Type B Investigation of Employee Puncture Wound at F-TRU Waste Facility

TO: Jeffrey M. Allison, Director of Special Projects

You are hereby appointed Chairperson of the subject Type B Accident Investigation (AI) Board that I have convened. Your investigation and report shall conform to the requirements detailed in DOE O 225.1A, Accident Investigations. Due to the continuing employee medical treatments, resulting delays in establishing a definitive assigned dose, and the potential significance of these type injuries, I have determined to conduct this investigation under criteria 5.b, Other Effects, prior to resumption of operations.

The Board will be comprised of the following members:

Mr. Jeffrey Allison	Accident Investigation Board Chair
Mr. Mark Smith	Accident Investigator
Mr. David Sanders	Health Physics
Mr. William Dennis	Program Management
Mr. J. J. Hynes	Operations

The scope of the Board's investigation is to include, but not be limited to, identifying all relevant facts; determining direct, contributing, and root causes of the incident; developing conclusions; and determining judgments of need to minimize event recurrence. Due to the extensive investigations already conducted by the contractor, the Board is encouraged to draw on and take full advantage of the work already completed to minimize duplication of efforts. The scope of the investigation is also to include DOE direction and oversight activities and any role they may have contributed to the event. In this context, DOE includes DOE-SR, Headquarters, and the Carlsbad Field Office.

The Board is expected to provide my office periodic reports on status of the investigation however no findings or premature conclusions should be released prior to completion of the causal analysis. Additional resources are available to support the Board as needed. Please submit draft copies of the factual portion of the investigation report to my office and to the affected contractor for factual accuracy review prior to finalization. The final report should be provided to me within 30 days of the date of this letter. Discussions of the investigation and copies of the draft report will be controlled until I authorize release of the final report.

If you have any questions, please have your staff contact me at 803 952-9468.

Jack R. Craig
Acting Manager

OSQA:CE:st

OSQA-10-0155

Barrier Analysis

Hazard: Transuranics **Target: Worker's Hand**

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Kevlar Gloves	Failed	Not Used Not designed to be puncture proof	Allowed puncture wound and Pu-238 injection
HyFlex Gloves	Failed	Not Used Not designed to be puncture proof	Allowed puncture wound and Pu-238 injection
Leather Gloves	Failed	Not designed to be puncture proof	Allowed puncture wound and Pu-238 injection
Anti-contamination Gloves	Failed	Not designed to be puncture proof	Allowed puncture wound and Pu-238 injection
Enclosure	Failed	Not designed to be puncture proof	Allowed puncture wound and Pu-238 injection
Fresh Air Hood	Worked	N/A	N/A
Localized Ventilation	Worked	N/A	N/A
ΔP Gauges/Negative Ventilation	Worked	N/A	N/A
Equipment	Failed	Proper (safe) equipment was not selected for the hole indicating task	Allowed puncture wound and Pu-238 injection
Waste Remediation Technician	Failed	Technician did not realize he was creating a new hazard (sharp) by modifying equipment. Technician did not understand the hazards associated with working with transuranics. Technician did not follow demonstrated installation method and did not notify management about concerns the survey flag would fall out of the one-quart can.	Allowed puncture wound and Pu-238 injection
Control Area Camera	Failed	Camera was not focused on Technician during this activity because it was not considered critical.	Missed opportunity to identify an unsafe work practice

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Use Every Time Procedure 221-F-55006	Failed	Did not include all controls from the AHA Did not contain clear concise direction installation of survey flags as hole indicating devices Facility management did not ensure appropriate review of procedure changes	Allowed puncture wound and Pu-238 injection Allowed puncture wound and Pu-238 injection Missed opportunity to identify hazards and appropriate controls
AHA	Failed	Did not identify the survey flag as a sharp Process for review and approval was inadequate	Allowed puncture wound and Pu-238 injection
Industrial Hygiene Controls	Failed	No formal process to link industrial hygiene controls (HyFlex gloves, nitrile gloves, thickness of glovebox gloves) to the AHA and disposition in procedures	Missed opportunity to evaluate and ensure appropriate PPE for the work
RWP	Worked	N/A	N/A
Safety Reviews (FAI-51)	Failed	Not conducted for any tools/equipment used in the Enclosure	Missed opportunity to identify a hazard and implement appropriate controls
Verbatim Compliance	Failed	Technician did not wear the full complement of gloves prescribed by the RWP. Technician did not follow demonstrated method of installing survey flag Technicians were chronically challenging sharps instead of using tools Management did not reinforce the importance of disciplined operations	None Allowed puncture wound and Pu-238 injection Allowed puncture wound and Pu-238 injection Missed opportunity to ensure expectations for disciplined operations were met

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Job-Specific Training	Failed	Personnel were not properly trained commensurate with their duties and responsibilities. Adequate training was not provided for survey flag installation. Facility management did not engage the Training organization in procedure reviews	Missed opportunity to ensure personnel understood the hazards associated with the TRU remediation work. Allowed puncture wound and Pu-238 injection Missed opportunity to develop formal training for new hazards and controls
Pre- and Post-Job Briefings	Failed	Sharps not discussed in detail; little worker involvement in conduct of pre-brief. Lack of management expectations on conduct of pre-brief Post-Jobs were ineffective	Missed opportunity for WRTs to voice concern on the retention of flag in can Missed opportunity for management to identify unsafe work practice Missed opportunity for management to identify unsafe work practice
Management Oversight	Failed	Management did not effectively oversee the performance of work Management did not recognize repeated failures as a chronic trend	Missed opportunity for management to identify unsafe work practice Missed opportunity to institutionalize meaningful corrective actions
Conduct of Operations Mentor Program	Partially Worked	Management failed to analyze, track, trend, and take action on issues identified by the Mentors.	Missed opportunity to correct unsafe work practices
DOE (Management, Facility Representatives)	Worked – DOE identified numerous issues and formally transmitted to the contractor	N/A	N/A
Puncture/Laceration Wound Hazard Management Program	Partially worked	Weak administrative procedure	Program not effective in emphasizing hazards or controls Positive – No spread of contamination
DSA (Consolidated Hazards Analysis Process)	Worked	N/A	N/A
Readiness Reviews/FEB	Partially worked	Management did not recognize repeated failures as a chronic trend	Missed opportunity to institutionalize meaningful corrective actions

What were the barriers?	How did each barrier perform?	Why did the barrier fail?	How did the barrier affect the accident?
Personnel experienced with glovebox operations (skill mix)	Partially worked	Personnel had limited to no experience with glovebox operations or work with transuranics	Increased the likelihood of accident due to inexperienced workers
Time out/Stop Work	Failed	Time out/stop work not consistently used after unusual events occurred Not reinforced by management	Missed opportunity to correct inappropriate behavior and reinforce positive expectations
ORPS/Lessons Learned	Partially worked	Some but not all corrective actions were implemented	Missed opportunity to identify hazard and implement controls
Self-Assessments	Partially worked	Did not identify the hazards associated with use of the survey flag	Missed opportunity to identify hazard and implement controls

Change Analysis

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect on this Accident
Engineered controls limited to ventilation with alarms and the special process Enclosure.	Effective use of engineered controls (hands-off, robotics).	Devices not used to perform work.	Allowed hands-on work to occur.
All hazards not identified during the Consolidated Hazards Analysis Process, AHA, Work Force Hazard Characterization, RWP, RTR, radiological evaluation report, drum characterization, or mockup training.	All hazards identified prior to commencing work.	Survey flag not identified as a sharp. Waste not fully characterized Additional tools not analyzed	Allowed sharp to be used without mitigating controls. (Direct Cause) Waste characterization was a driver for the task None
Non-SRS technicians; skill mix high ratio of non-experienced to experienced workers; First Line Managers, and Operations Manager were detailed to the task; radiological protection personnel had no TRU experience.	Use of experienced technicians and supervisors.	Technicians were not experienced in TRU work.	Allowed work to be conducted without a full understanding of the hazards and associated consequences resulting in a less than fully cautious approach to work in the Enclosure.
Procedure was less than adequate.	Prescriptive procedure in place.	Procedure contained vague and conflicting information.	Allowed different methods to be used to install survey flags.
Management provided informal training on survey flag installation during briefings.	Formal training on flag installation provided, including installation into one-quart cans.	No formal training was provided on survey flag installation into one-quart cans.	Allowed technicians to develop their own methods for installing survey flags.
Survey flag hazard analysis was informal and not in accordance with Procedure 8Q122. Workers given informal brief on Pu-238, flag not recognized as a sharps hazard.	Survey flag subject to proper hazards analysis prior to use. Workers have adequate knowledge of job hazards.	Sharp introduced into work area without specific controls. Less than adequate knowledge of Pu-238 and sharp hazards.	Missed opportunity to formally analyze a sharp (hazard). Technician injury occurred. Allowed technician to develop alternate work procedures without realizing the consequences.
Camera coverage was limited.	Full camera and audio coverage of control area (recorded).	Observers did not see technician bending or inserting the flag.	Missed opportunity for a time-out / stop work.
Post-job briefings were informal and infrequent.	Effective post-job brief conducted.	Feedback on survey flag installation issues not provided.	Missed opportunity to identify a field issue and take appropriate corrective action.

Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect on this Accident
Management was not in the work area.	Effective oversight provided in the work area.	Management oversight in the WCMA was not provided.	Missed opportunity to observe work practices and conditions in the WCMA.
Pre-job brief was conducted.	Effective pre-job brief conducted.	Technique to be used to insert the survey flag in a one-quart can was not specifically discussed and the flag was not identified as a sharp hazard to personnel. Workers did not actively participate	Missed opportunity to remind workers of proper survey flag installation technique. Missed opportunity to identify and correct an unsafe method of conducting work.
PPE in use.	PPE not needed due to engineered controls.	There was no full complement of engineering controls, therefore PPE was required. PPE in the procedure did not match the PPE specified in the Industrial Hygience Work Force Hazard Characterization document. All PPE prescribed in the RWP not worn by the Technician	Allowed injury to occur.
Mentor Program feedback not formally dispositioned.	Effective feedback provided and dispositioned including formal performance indicators, trending, and effective corrective actions.	No performance indicators other than monthly mentor notes; limited mentor contact with technicians; no formal tracking/trending. No performance analysis conducted to identify and correct deficiencies.	Allowed poor work practices to persist.
Less than adequate Conduct of Operations	Disciplined Conduct of Operations	Less than adequate operational formality and rigor.	Allowed inadequate control of work resulting in improper work practices.
Updated Documented Safety Analysis / Technical Safety Requirements were in place.	Effective Documented Safety Analysis / Technical Safety Requirements (hazard controls)	N/A	N/A

Events and Causal Factors Chart

Date/Time	Event	Comments/Conditions	Causal Factors (Key below)
February 2009	WIPP WAC requires "sealed containers >4 liters (nominal)" to be vented prior to shipping.		
July 2009	Preparations for current campaign begin with workers hired under ARRA.	Workers identified as Technicians vice Operators. Staffing was determined to include all ARRA workers as the crews, previous campaign workers temporarily promoted to First Line Managers, and a temporarily promoted Operations Manager.	
November 2009	Fast Scan (RTR) of the drums from E Area Pad 1 identifies liquid in containers as well as some inner cans bulging or split.		
March 2010	TRU Project Manager concerned with bulging inner cans based on WIPP WAC which precludes pressurized containers.		
3-07-2010	Per 2010-MFO-001567, cans were opened inside the Enclosure using a hammer-type chisel. Operations Manager discussed with Project Manager need for can puncturing device.		
3-11 – 18 2010	Need for "hole indicator" identified so WIPP can verify cans are vented prior to shipment from SRS.		
3-12-2010	Change to Documented Safety Analysis approves use of can puncture device.		
3-12-2010	Campaign shifts from waste segregation to include puncture of outer and inner cans, if liquid was identified.		
3-18-2010	Procedure 221-F-55006 (Rev. 31) revised to insert hole indicating device. Plastic wire tie is used; no specific method is defined.	Procedure stated only, "If containerized liquids are not present, THEN place hole indicator into can(s).	CC2 CC3
3-25-2010	Insulated wire replaces plastic tie wrap as the hole indicating device based on suspected inability of RTR to see plastic wire tie.	Insulated wire was the second hole indicating device to be used. No formal hazard analysis performed.	CC1 CC2 CC3
~3-31-2010	Insulated wire recognized as potential sharp and inadequately rigid.	Identified a need for another hole indicating device. No formal hazard analysis performed.	CC2

Date/Time	Event	Comments/Conditions	Causal Factors (Key below)
4-07-2010	Wire survey flags ordered as replacement for insulated wires for hole indicating device for cans.	No formal hazard analysis performed on selection of wire survey flags.	CC1 CC2
4-16 – 23-2010	Operations stopped due to smoking can event.		
4-16 – 23-2010	Workers briefed on use of wire survey flags and how to properly install them as hole indicating device.	Procedure did not contain specific instructions on survey flag installation. Formal training not provided. Briefing described use in one-gallon cans.	CC3 CC4
4-23-2010	Operations restarted, survey flags used as hole indicating device.		CC3
5-04-2010	Procedure 221-F-55006 revised (Rev. 32) to insert hole indicating device.	Procedure stated only, "Place hole indicator into can(s) or remove lid(s)."	CC3
5-13-2010	TRU Project Manager asks WIPP for technical basis for the expectation that containers <4 liters must be vented. TRU Project Manager determined to vent all cans due to difficulty in determining whether the cans were pressurized above atmosphere.	Venting was to verify there were no pressurized containers.	
5-14-2010	Procedure 221-F-55006 revised (Rev. 33).	Procedure required all inner cans to be punctured.	CC3
<u>2010-06-14</u> 0600 hours	Work reduced to two shifts due to reduction in workload.		
0635 hours	Pre-job briefing held.	Sharps were discussed, but the survey flag was not identified as a hazard to personnel. Workers did not communicate to management their concerns with survey flags not staying in the one-quart cans.	CC5 CC6 CC8
0940 hours	RPI entered work area to perform pre-work surveys		
1020 hours	Personnel entered work area with one 55-gallon drum containing one 30-gallon drum which contained five one-gallon cans containing five one-quart cans.		
1135 hours	While inserting the hole indicating device (survey flag) into one of the vented inner cans, WRT-1 punctured his right hand with the survey flag.	Survey flag had been cut. WRT-1 bent the survey flag into a "U" shape. WRT-1 applied pressure to insert the survey flag using his hand vice a tool.	DC RC CC3 CC4 CC5 CC6 CC7 CC8 CC9

Date/Time	Event	Comments/Conditions	Causal Factors (Key below)
1140 hours	The Shift Operations Manager was notified that a puncture wound had occurred in the WCMA.		
1155 hours	SRSOC contacted. RPI notified (paged) Internal Dosimetrist		
1202 hours	Emergency Management Services personnel arrive at the worker, RPI survey indicated 300 dpm alpha contamination at the wound.		
1208 hours	Emergency Management Services personnel left scene enroute to N Area with WRT-1		
1217 hours	Emergency Management Services personnel and WRT-1 arrive at 719-5N		

Causal Factors Key:

DC = **Direct cause** = A contaminated survey flag punctured the worker's PPE and hand, resulting in a radiological intake

RC = **Root cause** = A less than adequate graded approach used for high hazard TRU waste remediation work; this did not coincide with the discipline warranted for high hazard work.

Contributing causes were identified as follows:

CC1 = Management did not follow established protocols to ensure that Subject Matter Experts were involved in the identification and analysis of hazards.

CC2 = Management did not ensure that a formal hazard analysis was conducted for use of the hole indicating devices.

CC3 = The procedure did not identify a method for hole indicating device installation.

CC4 = Formal training was not provided on survey flag installation. Management demonstrated survey flag installation for one-gallon cans but did not provide additional training on one-quart cans.

CC5 = WRTs did not follow the demonstrated method of installing survey flags and did not notify management of their concerns that the survey flag would fall out of the one-quart cans.

CC6 = Management was unaware that alternate, unapproved methods of installing survey flags were being used.

CC7 = WRTs did not understand the safety significance of modifying prescribed equipment and not following survey flag installation as demonstrated.

CC8 = Management did not reinforce to workers the importance of disciplined operations, including use of time-outs and the need to discuss issues during pre- and post-job briefings.

CC9 = Known accident precursors were not adequately dispositioned and continued to exist in the workplace.

Opportunities for Improvement

- An opportunity for improvement exists in clarifying chelation therapy policy and procedures. Radiation Emergency Assistance Center/Training Site (REAC/TS) personnel from Oak Ridge recommended that the site doctor inject the chelating agent directly into the wound, but the doctor chose not to administer the drug in this manner as this was not a recommended means of administration according to the drug manufacturer. Additionally, WRT-1 did not receive chelation therapy on Day 2 due to issues related to patient availability. Had chelation therapy been provided, additional contamination could have been removed from the patient. (Section 2.3)
- An opportunity for improvement exists in the establishment of a permanent room or area at SRS dedicated to the treatment of contaminated wounds, stocked with the appropriate decontamination and medical/surgical equipment. (Section 2.3)
- An opportunity for improvement exists to ensure proper upkeep of the WCMA work area. The Board found that the WCMA work space was deficient in housekeeping and contained vast amounts of unneeded materials. The condition of the room presented a general safety hazard to the workers in the area. Workers in WCMA had not brought the condition of the room to management's attention, revealing a lack of understanding by the work crews regarding the room's hazards. The Board could find no evidence that anyone other than the work crews (e.g., management, previous start up assessment teams, or the Facility Evaluation Board) had entered the WCMA. An opportunity to identify and remediate the condition of the room was missed by the lack of management presence in the work area. (Section 2.6)

  Conditions found in the WCMA by the Board included:

  - Many sharps exist in the WCMA and are readily available for possible re-introduction into the Enclosure.
  - Extraneous tools similar to those prohibited in the Enclosure.
  - Numerous items exist in WCMA that appear to be left over from work prior to TRU Drum Remediation. Items include scaffolding parts, a scissors man-lift, and toolboxes.
  - No labeling of secondary containers for storage of chemicals.
  - Duct tape covering an apparent hole in the wall of the Enclosure.
  - An outdated program of expired enclosure glove date labeling.
  - No labeling of lead blankets installed on the bottom of the Enclosure.
- An opportunity for improvement exists in evaluating the risks associated with the TRU workscope. The current phase of the TRU remediation work involves Pad 1 drums from E Area. These drums range up to 1,800 plutonium equivalent curies. This accident involved a 328 curie drum. The Board found that no risk analysis had been performed for conducting the remediation work in an Enclosure versus other alternatives. As a result, the Board could not evaluate the basis for choosing to conduct the TRU drum remediation work in an Enclosure. A formal evaluation of the risk of continuing work in an Enclosure for higher curie drums versus alternative paths should be completed. (Section 3.2)
- An opportunity for improvement exists in evaluating the hazards and controls associated with work in the F-TRU Enclosure. During the investigation, the Board requested that an independent review of the hazards and controls associated with the Enclosure be conducted by the DOE-SR Assistant Manager for Nuclear Materials Stabilization Project, Nuclear Materials Engineering Division. Discrepancies were identified that indicate further review of the Enclosure design requirement, the crediting of controls identified in the Consolidated Hazard Analysis Process, and the controls brought forward in the Documented Safety Analysis and Technical Safety Requirements is necessary. The review also identified conflicting assumptions and

methodologies between radiation protection and accident analysis reviewers in the Consolidated Hazards Analysis Process related to dose calculations and their use in the hazards analysis (Section 3.4).

- An opportunity exists to improve ventilation controls in the WCMA. The Board evaluated WCMA ventilation controls as part of the investigation and found that administrative controls had been instituted on the "security" door during entry into WCMA. The controls were put in place as a result of an increase in air flow turbulence which had caused a spread of contamination (months prior to the accident) at the opened end (drum dumper area) of the Enclosure. The turbulence resulted from the shutdown of the Canyon Supply Fans during deactivation work. The corrective action implemented by the facility was to administratively control the opening of the "security" door by relocating personnel from the opened end of the Enclosure when the security door is opened. This administrative control prevents workers from immediately becoming contaminated or exposed to an increase in airborne radioactivity, but does not prevent contamination from being released from the open Enclosure into the work area. As a result, the Board determined that an evaluation of more robust control(s) is warranted, especially as the facility moves towards processing higher Pu-238 activity drums. (Section 3.4)

- An opportunity for improvement exists in the installation and use of video cameras in the WCMA Enclosure. There are two video cameras installed within the Enclosure and an additional camera targeting the WCMA outboard of the Enclosure. Camera images are projected on video screens at the Control Station in the WCMA Radiological Buffer Area. The camera located at the bag out port end of the Enclosure is the only camera feed that can be recorded and is the camera normally controlled by the procedure reader during work evolutions. The view from the camera at the drum tilt end of the Enclosure is blocked whenever a drum is tilted up for unloading. When the use of survey flags began on April 23, 2010, installation of the flags into the cans was performed by one WRT. For efficiency purposes, installation of the survey flags evolved to installation of flags into cans by three WRTs working in parallel. The arrangement of the cameras does not allow simultaneous observation of all three work stations in the Enclosure. The Board found that during remediation work, after the can puncture evolution was completed, the camera was typically targeted at the tray-in-pan arrangement to observe cleaning of the tray. The Board determined that installation of the survey flags was not considered a critical step or a hazardous activity by management, and the activity was therefore not necessarily observed or recorded on the video. During the contractor's root cause analysis performed after the accident, SRNS self-identified an action to install additional cameras and monitoring equipment to provide the capability to monitor all processing positions simultaneously. However, SRNS did not consider this corrective action to be required to be complete prior to resumption of remediation activities. The Board determined that installation of the necessary cameras to enable monitoring of all WRT work activity in the Enclosure should be completed prior to resumption of evolutions involving simultaneous work at multiple stations. (Section 3.5)

- An opportunity for improvement exists in ensuring that feedback from the ARRA Conduct of Operations Mentor Program is formally shared, tracked and trended to effect lasting improvements in performance. The Conduct of Operations Mentor Program was in place at the time of the accident, governed by a program document, *ARRA ConOps Mentor Program*, dated September 1, 2009. The intent of the Mentor Program was to provide additional defense-in-depth to ensure ARRA work was performed safely. Mentors were assigned with the work crews to help them maintain the appropriate rigor in the implementation of work. They gave no direction to the work crew unless an imminent safety situation required action. Mentors maintained a log of positive and negative observations of F-TRU work. A Board review of the mentor log revealed that mentors regularly identified issues requiring resolution on shift and also identified positive attributes of the work. The logs were maintained electronically and observations were de-briefed to upper project management personnel on a regular basis (nominally monthly). This log was not widely distributed. The Mentor Program was not designed for mentor issues to be tracked in the company's deficiency database. As a result, issues identified by the mentors were not formally tracked to closure. Additionally, no formal performance indicators were established to enable tracking, trending, or forecasting of performance. (Section 3.5)

- An opportunity for improvement exists in finalizing and issuing an assessment plan for F-TRU waste remediation activities. SRNS implements the self-assessment process in accordance with Manual 12Q, *Site Assessment Manual,* Procedure SA-1, *Self-Assessment*. On January 12, 2009, the "Area Completion and Solid Waste Management 2009 Self Assessment Plan" was issued and covered the period from January 5, 2009, through February 28, 2010. On March 10, 2010, the "Fiscal Year 10 ARRA Integrated Self Assessment Plan" was issued. These plans assigned assessors responsibility for covering a wide array of assessment topics, but did not necessarily identify specific areas within the various ARRA projects in which to perform the assessments. In April 2010, the F-TRU Project Manager self-identified that a separate assessment plan was needed for F Area TRU Projects. However, at the time of this report, no separate plan had been issued. Prompt issuance of a specific F-TRU assessment plan would be prudent to better define oversight expectations for F-TRU remediation work. (Section 3.6).

- Opportunities for improvement exist in the training and qualification for workers involved in F-TRU waste remediation work: (Section 3.7)

    - Procedure PROGQRPOPDES000114, *Radiological Protection Department, Training and Qualification Program Description*, dated June 2010, states in Figure 1 of Section 6.6.2 that the training period for a Radiological Protection Inspector (RPI) is 24 months. Section 6.12.1, *Subcontractor Entry Qualifications*, states that subcontractor personnel shall have 3 years prior experience as a Radiological Protection Technician/Inspector to perform RPI duties. The procedure further states that resumes should be reviewed to identify personnel with experience in jobs similar to those for which they will be employed. Through interviews, the Board found that all of the subcontract RPIs interviewed stated they did not have previous experience with Pu-238 or with the handing of TRU waste. Through interviews, the Board determined that the training period for subcontract RPIs was shortened from the time period required for a direct hire employee serving as an RPI. While the prior work experience of the subcontract RPIs provided a base knowledge regarding routine radiological control work activities, it did not provide them with an appreciation of the specific hazards associated with the F Canyon remediation work. The Board determined that the RPIs' lack of knowledge related to the hazards associated with the work scope resulted in missed opportunities to identify and address accident precursors.

    - A review of training records disclosed that persons assigned as Senior Supervisory Watch (SSW) did not receive a qualification briefing, nor were expectations for this activity established by the Area Project Manager in accordance with SRNS Manual 2S, *Conduct of Operations*, Procedure 5.1, Rev. 6. The procedure also recommends the use of an SSW evaluation sheet to determine whether an individual is suitable for the SSW assignment. The procedure also states that the "Person-in-Charge" (PIC) should be selected based on their knowledge, skill and experience. The Board found that the selection process used for the SSWs and PICs for the TRU Waste Remediation Project was not as rigorous as other established programs at SRS. The Board determined that the selection process and lack of clear expectations for the SSW and PIC positions resulted in missed opportunities for these individuals to identify and address accident precursors.

- The Qualification Cards for Radiological Protection Inspectors and for waste drum handlers did not require completion of F-TRU Waste Remediation Hazards Awareness Training (ZFAIXB01). This classroom training provides workers with an understanding of the hazards associated with Pu-238 and should be required for all workers whose tasks may involve work with this material.

Test Plan for Analysis of the Leather Overglove and Hole Indicating Device in use at the time of the FCC TRU Drumline Puncture Incident (U)

August 2010

SRNL-L7000-2010-00020
Revision 0

Approvals:

FCC TRU Drumline DAE: ____________________ 8-20-10
J.B. Schaade Date

SRNL Material Science & Tech.: ____________________ 8/20/2010
R.L. Bickford Date

Test Plan for Analysis of the Leather Overglove and Hole Indicating Device in use at the time of the FCC TRU Drumline Puncture Incident

Background:

Upon receiving the punctured glove and hole indicating device (via Sample Receiving), SRNL will perform the following tasks in an attempt to determine if the overglove was degraded by chemicals, radiation or other factors such that it was less puncture resistant than expected. In addition, specific tasks will be performed to examine the hole indicating device involved with the puncture incident. This work has been requested by Technical Assistance Request # S-TAR-F-00002 and # S-TAR-F-00003. These tasks are considered non-baseline and R&D. Approval was obtained from the customer (J. Schaade) to perform destructive testing if deemed necessary to obtain the requested information. Tasks will be performed nondestructively to the extent possible to preserve material for future evaluation if necessary. All samples will be maintained in a TRU drum after examination until further instructions are provided by the customer.

Please note that this is considered to be a living document, and testing methods may be changed based on results and customer requests.

1) As-Received Glove Condition Documentation:

The as-received glove will be digitally photographed at the time of receipt, including packaging and labels as appropriate, and at any points of transfer within the laboratory for chain of custody. Receipt and transfer of the glove sample will be performed in accordance with existing procedures. The glove will be assigned an ADS LIMS sample # for tracking purposes.

2) Counting Facility:

Upon receipt, the glove will be transferred to (in the as-received packaged condition) the ADS counting room for radiological evaluation. The transfer will be visually documented/photographed. Depending on the packaging configuration, the analysis could take a day. Analysis in the as-received condition is preferred to minimize potential for contamination if packaging layers are removed. This step is being performed to assess the level of contamination present on the glove and to determine isotopics. This may be useful in evaluating the potential for radiolytic degradation.

3) Visual/Microscopic Evaluation:

After leaving the ADS counting facility, the glove will the n be transferred to the glovebox in 773-A, C-059. This glovebox contains a calibrated stereoscope (1-64X) and digital photography capability. Transfer of the glove into the glovebox will be visually documented. During this step, the glove will be visually examined in various orientations and magnifications as needed. The overall condition of the glove, surface texture, and all aspects deemed relevant will be documented. The puncture area will be given specific consideration. Photographs taken at various angles and magnifications may be needed. The puncture area will be flexed and examined to the extent practical without causing further damage to the puncture site, in case the puncture area is needed for future examinations.

Comparable photographs will be taken of a representative glove of the same style/model # for visual comparison using the same equipment in the same lighting environment within the glovebox.

The thickness of the leather in puncture area will be determined via optical /calibrated stereoscope if possible. Physical measurement using a magnetic film thickness gauge may be performed if needed (metal shims placed in side glove at puncture area and thickness measured with gage. A demo will be performed to ensure that set-up works in the glovebox.)

The glove will be flexed and examined for signs of degradation (abrasion, staining, surface cracking, reduced flexibility, surface debris/sloughing off of material during handling, etc.) in relevant areas (palm, finger, puncture location). Similar areas on a new ILP-3S leather overglove will be similarly examined. Observations will be recorded.

4) FTIR/Raman Spectroscopic Analysis, Water Leaching and IC:

Upon completion of physical/visual examinations, a representative sample of required minimum size (at least 5 mm x 5 mm) in at least one area will be sectioned/cut and submitted for FTIR (Fourier Transform Infrared) and Raman spectroscopic analysis. A proposed section is the top of the middle finger (or lower portion if visual observations indicate signs of degradation such as staining), as this area is reasonably believed to have seen similar exposure to the puncture area. This represents the glove material while preserving the actual puncture location in case further analysis is required. Pending radiological approval, finger samples will be submitted to EM for FTIR spectroscopic analysis. FTIR and Raman spectroscopy are used to identify chemical species that may be present on the gloves, as well as analyzing the chemical/molecular structure of the leather/collagen-based material. Comparisons to samples from a new ILP-3S glove will be made to allow baseline information from new gloves 10 be appropriately considered in the evaluation.

If for some reason, FTIR or Raman analysis cannot be performed in a separate hood, samples will be examined within the glovebox via a probe connection and pass through ports. This will provide similar analysis but with lower resolution. FTIR/Raman analys is outside the glovebox is preferred for best resolution. Analytical will perform water leaching and IC if results from FTIR indicate this is needed. Customer approval will be obtained prior to water leaching and IC being performed.

5) Mechanical/Puncture Testing:

If evidence obtained from previous tasks sufficiently addresses the issue of potential degradation of the leather overglove, no further evaluation may be needed. Customer approval will be obtained prior to deciding not to perform puncture testing. If previous analysis is not sufficient or does not provide conclusive evidence, additional tests may be needed to evaluate the mechanical properties of the glove. The presence of chemical species from incidental exposure alone mayor may not have significantly affected the relevant mechanical properties of the glove. Specifically, the puncture resistance of the overglove in the punctured area or similar locations are of interest. Since the actual punctured area is in upper palm section of the index finger, it is expected that similar glove sections from the other fingers would be suitable for puncture testing.

The proposed test method would in volve an arbor press small enough to fit through the glovebox port openings (or in sections to be assembled in the glovebox). A dial indicator or calibrated torque wrench shall be used to indicate the force applied to puncture a sample of leather glove material. The device will be demonstrated in a clean glovebox for repeatability and ease of use within a contaminated glovebox. Probes as used for ASTM Fl342 will be used to baseline the new equipment (with new gloves) to previous testing. Actual testing of the glove sample will done using a new hole indicating device and the hole indicating device involved with the puncture incident (old hole indicating device). It is envisioned that 3 punctures of the glove sample will be done with a new hole indicating device and 3 punctures will be done with the old ho le indicating device. In addition, testing of a new glove sample will be done in the same fashion using a new hole indicating device and the old hole indicating device. All total, 12 punctures will be performed and used to evaluate the performance of the glove samples.

Due to the nature of leather with variation in grain orientation and thickness, the individual puncture force value can vary significantly. This leads to doing multiple (3) punctures with each hole indicating device. Samples will need to be constrained during testing to minimize deflection. Due to the inherent variables in mechanical testing coupled with leather being a natural material, there is no guarantee that mechanical/puncture testing alone can provide conclusive evidence of leather degradation. Such data may al so be inconclusive due to the unknown condition of the overglove at the time of the puncture incident compared to the as-received condition of the overglove, possible effects of storage environment prior to receipt at SRNL and other factors.

6) Hole Indicating Device Examination:

The as-received hole indicating device will be digitally photographed at the time of receipt. Receipt and transfer of the hole indicating device will be performed in accordance with existing procedures. The hole indicating device will be assigned an ADS L1MS sample # for tracking purposes and transferred to the glovebox in 773-A. c- 059. This glovebox contains a calibrated stereoscope (l-64X) and digital photography capability. While in the glovebox, the hole indicating device will be visually examined in various orientations and magnifications as needed. The overall condition of the hole indicating device, especially the end opposite the flag, will be photographed and documented. The condition of the end of the device, whether blunt or pointed or cut is of specific interest. The overall length of the hole indicating device, from tip to tip, will be measured as well as the diameter of the wire. Photographs will be taken at various angles and magnifications as needed.

7) Data Analysis, Report Writing and Peer Revi ew:

Results will be documented in a TR report by the Team Lead (Bill Daugherty) and various researchers. Report will be issued to F-Area personnel (J. Schaade, S. Engelberg).

Savannah River National Laboratory Results of Analysis

SAVANNAH RIVER NATIONAL LABORATORY

SRNL-L7200-2010-00019

August 30, 2010

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FCC TRU Drumline Punctured Overglove Investigation Results (U)

Summary

As a result of a glove puncture and contamination incident in the F-Area TRU facility, SRNL was requested to analyze the punctured glove and determine if the glove was potentially degraded by chemicals, radiation or other possible factors. The puncture incident involved a wire landscape flag used as a hole indicator device (HID) to provide visual/radiographic evidence that waste containers were not pressurized prior to final disposition. The HID involved in the incident was also submitted for evaluation. Visual and physical examinations, and infrared and Raman spectroscopic analyses were performed.

Based on the test results, SRNL concludes that the LP-3S leather overglove from the TRU facility was not significantly degraded compared to a new glove of the same model. The

properties of the glove relative to puncture resistance are therefore expected to be comparable to other new gloves of the same model. Accordingly, on August 27, 2010, SRNL and the F-Area TRU Facility recommended that further efforts to characterize the glove (e.g. puncture and leach testing) should not be pursued further. DOE subsequently concurred with this recommendation. This memorandum documents the data and analysis that support these conclusions and recommendations.

Introduction

A worker in the F-Area TRU facility sustained an injury and internal contamination due to puncture of the personal protective equipment (PPE) while performing work in the TRU remediation enclosure (RE). The PPE reportedly worn in the F-Area TRU facility at the time of the incident consisted of the following layers (outer layer first):

- 1 pair, Salisbury leather linesmen overgloves (Model LP-3S)
- 1 pair, Piercan 8UY2032-10.5 glovebox gloves (20-mil Hypalon®/polyurethane)
- 1 pair, Kimberly-Clark KC-300 nitrile gloves
- 2 pair of latex gloves
- 1 pair cotton liners

The Salisbury leather overglove (LP-3S, Figure 1) is primarily marketed as a linesman overglove to protect electrical insulating gloves from mechanical damage and abrasion. The Salisbury gloves are fabricated to ASTM F696 [1]. The leather used for the gloves must meet military specification DLA MIL-DTL-32092 [2]. Neither standard includes a puncture resistance requirement.

SRNL was requested to analyze the punctured glove and determine if the glove was potentially degraded by chemicals, radiation or other possible factors, in support of the DOE Type B Investigation. This work has been requested by Technical Assistance Requests # S-TAR-F-00002 and # S-TAR-F-00003 [3, 4]. The glove and hole indicator device (HID) reportedly involved in the incident were shipped to the SRNL sample receiving on August 16, 2010 for analysis.

Test Plan

The planned scope of investigative activity included the following tasks. This scope was identified in an approved test plan [5].

- Gamma pulse height analysis of glove as-received (still bagged)
- Visual examination of glove and HID in glovebox, at up to 25X magnification
- Photographic documentation of visual examination
- Section glove for later tasks
- Measure thickness of glove and HID
- Spectroscopy (FTIR and Raman) of finger removed from glove
- Leach testing of second finger removed from glove (as needed)

- Puncture testing of glove (as needed)

For each of the test steps, a new LP-3S glove was also tested for comparison. A number of new gloves were provided by the facility for this purpose.

The planned leach testing was deferred pending the outcome of spectroscopic analyses. Subsequently, it was decided to not pursue leach testing based on the minimal additional information likely to be learned from that process.

Preparations for puncture testing were followed in parallel with the other efforts. However, following collection and analysis of the spectroscopic data, the SRNL team and customer jointly recommended to the DOE Investigative Team that the puncture testing not be performed. The DOE team concurred with this recommendation.

Results and Observations – Visual and Physical Examination

The overglove was stored with other radioactive waste for approximately 7 weeks from the time of the puncture incident until it was provided to SRNL. It is unknown how long the overglove had been in service prior to the incident, since the overgloves are replaced only as needed to maintain reasonable background exposure to the operator's hands. Degradation due to chemical exposure and radiation could have occurred during service, or during the subsequent storage period. As a result of this history, it is indeterminate whether any observed degradation occurred prior to the puncture or during subsequent storage.

Gamma Pulse Height Analysis

Counting information on the packaged, as-received glove is shown in Table 1 (for LIMS Sample s75384, notebook reference SRNS-NB-2008-00020, page 94). The glove exhibited total activity levels of 5.6 E9 dpm, with the large majority of contamination due to plutonium-238, which emits alpha radiation. Hence, one expects radiation damage to manifest primarily near the surface layer of the gloves since 99.7% of the radiation is from alpha emissions.

With less than 3 mCi of total radioactive material on the as-received glove, the radiation dose seems relatively limited. The exact dose and time in service is unknown. However, SRNS Engineering personnel reported that normal operating protocol involved replacement of overgloves based on a probe reading of >/= 50 mrem.

Visual/Microscopic Evaluation

The glove was triple-bagged, as-received. It had been placed relatively loosely within the first bag, which in turn was folded together by the subsequent bagging operation. Upon opening the bags, the glove was found to be flexible, and had not taken a set from its positioning within the bags.

It was noted that none of the bags contained any visible moisture or condensation. The glove itself appeared to be dry. Therefore, it is likely that the glove was not significantly wetted during the 7 week period it was stored prior to delivery to SRNL.

For reference, a new, clean leather overglove of the same model (Salisbury LP-3S) is shown in Figure 1. The punctured overglove is shown in Figure 2. The punctured glove was examined visually and at low magnification (5 and 25X) under a stereo microscope. The puncture region is shown in Figures 3-4.

During examination of the glove to identify and photograph the puncture location, the glove was flexed and manipulated to a limited extent. During these operations, the glove was noted to feel and act very much like a new glove.

The HID received from F Area is shown in Figure 5. For comparison, a typical landscape flag is shown in Figure 6. The end of the HID had been cut off by the facility prior to use (reducing the total length from ~20 inches to ~16.6 inches). While a new landscape flag has a flat end cut square to the wire axis (Figure 7), the HID has a mostly flat end at a slight angle relative to the new landscape flag (Figure 8).

Sectioning of glove

Upon receiving approval to proceed with destructive examination activities, the glove was cut with scissors. The middle finger and ring finger were cut off for spectroscopy and leach testing, respectively. The cuff was cut off, and the remaining material was cut along a side seam to allow it to open out as a single leather layer.

The manner and ease with which the glove cut was observed to be very similar to that of cutting a new glove, and new gloves were subsequently cut by the same personnel in a similar manner to provide a specific point of comparison. There was no cracking, crumbling or fraying of the leather as it was cut.

Measure thickness of glove and HID

Once the glove was cut open, the thickness of the leather was measured at three locations around the edge (Figure 9). Measurements were performed with the stereo microscope. Results are shown in Figure 10.

Measurements of the F-Area HID diameter were made with the stereo microscope. The average thickness of the HID converts to 0.068 inch. Results are shown in Figure 8, and are consistent with data from the new flag. The nominal diameter of a typical flag was previously measured as 0.066", which roughly corresponds to an American Steel and Wire Company size 15-16 gauge wire. The wire flag hardness was determined on a new flag as approximately 39HRC (converted from microhardness).

Results and Observations – Spectroscopic Examination

Understanding Chemical Nature of Overglove and Possible Attack by TRU Process Chemicals

The overglove is manufactured using domestic leather in apparently a multiple step tanning process. Cutting through the leather exposes an apparent tri-layer material. The outer and inner layers have a distinctly more pronounced yellow color. Examination of the cross sectional area of a new glove (see Figure 11) indicates the exterior layer (on the palm side) has a thickness of 90 – 122 microns or approximately 6.4 - 8% of the entire thickness; the inner layer adjacent to the skin in normal use measured approximately 250 microns, or 17.9% of the overall thickness.

The chemical nature of the TRU waste processing line is not well understood. Quite likely, some waste derives from historical site "wet" processes that include exposure to nitric acid, possibly with hydrofluoric acid, while other waste may have been exposed to caustic solutions used to adjust the pH or neutralize the wastes.

To understand the impact of these potential chemical exposures, samples from a new vendor glove were exposed to various solutions, removed from solution allowing to dry, and the surfaces then analyzed by spectroscopic means.

Contaminated Overglove Sample Preparation for Spectral Analyses

Small segments, approximately 1 mm by 2 mm in area, were cut from the middle finger of the TRU waste processing glove. No deliberate attempt was made to remove the surface debris. Cutting did not release any significant fibers or cause any significant fraying, suggesting good mechanical integrity of the material. (The cutting appeared much the same as that of a new glove.)

The middle finger was selected for its relatively close proximity to the puncture site and with the assumption that this finger likely experienced a similar or greater degree of mechanic usage and contact with the TRU waste. The general appearance of the glove exterior surface shows grime, more heavily deposited on the palm surface. The overall coverage of the surface is somewhat spotty and the deposits are not extensive; the glove appears to have had relatively light usage. Table 1 indicates the total mass of deposited radionuclides at <0.2 mg.

In glovebox containment, the cut segments were encapsulated between two KBr (potassium bromide) glass plates. During encapsulation, the plates abraded or moved the exterior debris to some extent as evidenced by scratches on the KBr plates observed by microscopic imaging. The samples were oriented to expose the exterior of the palm surface, the exterior of the backhand surface, and the interior of the palm surface. The two glass plates were taped together to seal the radioactive sample.

The exterior of the sealed sample was then wiped to remove excess contamination and the source removed to an adjacent radiological hood through a transfer port. In the hood, the source was again encapsulated by an additional two glass plates with tape holding the circular plates in position. A surface smear was performed and examined for radioactivity. The survey indicated no radioactivity on the exterior of the sealed surface.

The new glove was examined without encapsulation due to the urgency of time, but previous examination of encapsulated samples indicated no significant loss of resolution.

The encapsulation did provide less optimal sample orientation for microscopic imaging. Also, the presence of the plates resulted in less distinct spectra than observed with the non-encapsulated new glove. The depth of penetration for the FTIR analysis is estimated as 40 – 60 microns. (The entire thickness of the leather is ~1,400 microns. Hence, the FTIR analysis analyses the 2.9 – 4.3% depth of the material on either side; or a total of 5.8 – 8.6% of the total thickness.) Hence, the use of difference spectra is less reliable due to the increase in "noise" from these variations.

In the case of Raman interrogation, the leather is subject to degradation from the laser energy. As a result, laser power was reduced to 25% of that typically used thereby limiting the quality of those spectra. The depth of penetration for the FT-Raman analysis is estimated as 0.25 microns.

Given those limitations, relatively good signals and spectra were obtained.

Analysis of Chemical Environment

Figure 12 shows the impact of the chemical exposure to a new glove. Short-term (2 hour) exposure to a mixture of 0.001M nitric and 0.1M hydrofluoric acid showed incorporation of fluoride into the organic structure (as evidenced by appearance of peaks at 1100 cm^{-1} wavenumbers) as well as nitration of the organic (as evidenced by appearance on peaks at 1550 cm^{-1} wavenumbers). (Review of literature spectra for pure KF and NaF solutions [6] shows no peak occurs at 1100 cm^{-1} wavenumbers indicating that the new features are not simply from deposition of KF crystals on the dried leather surface.) Also, visual inspection of the leather surface indicated "dimpling".

The FTIR analysis of the overglove (see Figures 13 and 14) from the TRU Drumline did not show similar features. There is a slight broadening of the native peak near 1100 cm^{-1} wavenumbers but no evidence of nitration.

Exposure of a new glove to either 2M nitric acid or caustic (for periods of 20 min) showed obvious swelling of the leather with discoloration. These exposures also resulted in the incorporation of new chemical moieties into the leather as evidenced by peaks in the FTIR spectra. Figures 13 and 14, of the contaminated overglove, do not show these features nor does the microscopic imaging show evidence of swelling for the leather.

The new vendor glove (see Figure 11) shows a thiosulfate peak at 1000 cm^{-1} wavenumbers for the exterior layers that is missing in the bulk of the material (i.e., the "middle" layer). The thiosulfate is very likely from sodium thiosulfate, which is commonly used as a reducing agent in the chromium tanning process and contributes to the yellow coloration. Figure 13 shows a 150X magnified view of the palm side of the middle finger cut from the glove of the puncture incident. FTIR analysis of the solids on the overglove (i.e., the "grime"), shows presence of hematite (i.e., iron oxide), uranium oxide, silica, and nitrates or nitrites. In areas where the encapsulating process for the sample had displaced the grime, FTIR analysis of the underlying leather showed loss of the thiosulfate. FTIR of the areas that had not seen apparent deposition of the grime did not show as much loss of the thiosulfate group. These data are interpreted as suggestion of rather limited chemical attack of the glove from the TRU Drumline.

Looking for Evidence of Radiolytic Attack

A limited literature review identified only a weakly relevant article on impact of radiation on leather [7]. Preservation efforts for leather artifacts can include the use or irradiation (for example gamma radiation by ^{60}Co) to typical doses of 25,000 Rads.

Given that the radiation for the surface deposits is almost exclusively from alpha-emissions, it was reasoned that the best, readily available tool to search for structural changes from radiolytic attack was Raman spectroscopy. This method exclusively looks at the top few microns of the material and stresses the carbon-carbon bonds. In this application, the Raman laser used required reduction to ~25% of power to avoid burning the leather surface and hence penetrated to an estimated depth of only 0.25 microns. Comparing the FT-Raman spectra for the new and contaminated glove (see Figure 15) one notes primarily a change near 1667 cm^{-1} wave conenumbers which corresponds to formation of a carbon-carbon double bond (-C=C-). The magnitude of the change is judged as small. Furthermore, the same shift is not apparent in the corresponding difference FTIR spectra which penetrates ~40-60 microns into the surface. Hence, given the relatively low curie content of the solid deposits and limited evidence of deep formation of the double bond, it is concluded that radiolytic damage is relatively limited and unlikely to impact the bulk property of the glove.

Judging Mechanical Integrity from FTIR Analyses

Recent studies have linked the degree of degradation of parchment – or leather – to changes in features of the FTIR spectra [8, 9]. Leather is composed in part of collagen and this particular leather has distinctive FTIR spectral features designated as the Amide I (near 1650 cm^{-1} wavenumbers) and Amide II (near 1540 cm^{-1} wavenumbers) regions. Leather (and collagen) deteriorates through three prime means: denaturation, hydrolysis and oxidation [8]. The studies indicate that as these reactions proceed the relative peak areas of the Amide I and II regions and the space distance between the peak centers changes. Figures 14 and 15 show changes in this spectral region when comparing the new glove and the contaminated glove.

Peak heights and positions were determined from the spectrum of a new LP-3S leather glove and the TRU waste leather glove. After determining peak distance and relative peak height, those data were plotted in Figure 16 (from [9]) to determine the relative degradation of the TRU waste leather glove. Inspection of this figure reveals that the new glove (LP-3S) has relative very little hydrolysis and denaturation (shown in the "+" symbol). The TRU waste leather glove appears to have the same level of hydrolysis but a bit more denaturation (lost of protein order) than the LP-3S. In the same figure, data from the "Dead Sea Scroll" which is leather from 200-100 B.C. are also shown for comparison. The TRU waste leather glove data is in the same grouping as the reference leather data (lower left corner). Unfortunately, the scale in this figure is not directly linked to mechanical properties – such as puncture resistance. In addition, the relevance of these data for leather tanned by modern methods (i.e. chromium tanning) has not been established. Nevertheless, the variance between the new and contaminated glove shows no evidence on hydrolysis and is only slightly greater than that observed for the references samples in the referenced study. This limited variance in denaturation gives some confidence that the change in properties between the new and contaminated glove are comparable to lot-to-lot variations for leather materials.

Discussion

The specific goal of testing the punctured glove was to determine whether it had been degraded such that its puncture resistance at the time of the incident was impacted negatively. The following observations are made with regard to this question.

- The visual evidence (flexibility and general texture) is consistent with a new glove.
- The punctured glove has light to moderate staining over a significant portion of its surface, but there are no significant deposits of foreign material on the glove.
- The cutting characteristics of the punctured glove are similar to that of a new glove. This behavior is primarily a reflection of the leather shear strength, which would have a strong influence on puncture resistance.
- The FTIR spectroscopic analysis shows the chemical make-up of the leather to be substantially the same between the punctured glove and a new glove. The absence of surface coloration noted under surface deposits, if related to leather degradation, would impact no more than approximately 8% of the glove thickness. The slight broadening of some spectrum peaks for the punctured glove may indicate some damage to the molecular structure, but the general absence of additional peaks from potential break-down products suggests that such damage was minimal.
- The Raman spectroscopic analysis similarly shows very little difference between the punctured glove and a new glove. The most significant difference is a slight broadening of the 1638 cm^{-1} peak which may relate to the formation of double carbon bonds. This may indicate chemical or radiation damage, but the limited scale of this broadening indicates such damage would be minimal.
- The potential damage indicated by the Raman spectroscopy was not apparent in the FTIR spectroscopic analysis. The Raman interrogates the leather surface only (to a depth of ~0.25 μ), while the FTIR interrogates the leather to a depth of approximately 40 – 60 μ. Therefore, if the broadening seen in the Raman spectra represents actual damage, it was not present in, or relevant to, the bulk of the leather thickness.
- FTIR and Raman studies show little to no changes in chemical features for the punctured glove from suspected contact with acids and bases. Similar analyses for new gloves indicate the methods used would easily measure even limited exposure to those chemicals

On the basis of the evidence developed to date, it is concluded that the punctured glove is not significantly degraded relative to a new glove of the same model. While there are no specific data relating damage of the molecular structure to mechanical properties, the shear strength (cutting behavior), lack of any fraying during cutting, texture and flexibility of the glove show that its bulk mechanical properties are not significantly degraded.

With the conclusion that the puncture resistance of the glove was not significantly degraded, it is obvious that neither the service history of the glove prior to the puncture incident nor the storage conditions subsequent to the puncture incident led to significant degradation of the glove.

It is noted that the end of the HID is angled somewhat relative to the squared end of a new landscape flag. This configuration would allow the glove to be punctured more easily, since the angled end allows for a combination of cutting and shearing of the leather, while a square end would act primarily in a shearing mode. This effect would be expected to reduce the penetration force of the HID versus a new landscape flag in any glove. The forces involved at the time of the incident are unknown. However, regardless of the overglove condition, the force involved in the puncture incident was also sufficient to puncture the underlying Piercan 8UY2032-10.5 glovebox glove (20-mil Hypalon®/polyurethane) which has its own inherent puncture resistance.

Conclusions and Recommendations

The visual, physical and spectroscopic evidence all indicate that the puncture resistance of the punctured glove was not significantly degraded relative to that of a new glove. This conclusion is based on the evidence collected following storage as TRU waste for approximately 7 weeks after the puncture incident, but is equally valid for the condition of the glove at the time of the incident. Neither the service history of the glove nor the subsequent storage environment is believed to have significantly degraded the puncture resistance of the glove.

In the basis of the evidence accumulated to date, the SRNL team and F-Area TRU Facility recommended to the DOE Investigative Board that no further efforts be expended to characterize or test the punctured glove. This includes the cessation of activities relative to puncture and leach testing. DOE concurred with this recommendation on August 27, 2010.

Acknowledgements

The SRNL glove investigation team gratefully acknowledges the invaluable contributions from many individuals and organizations that allowed the safe and timely completion of the work described. Specific appreciation is extended to the J. Ziska and the MS&T and EM technicians (Garritano, Reown, Timmerman, Mealer), RPD, ROD, and Analytical Development personnel. Although not put into service, D. Fisher, 749-A machine shop and customer procurement personnel worked tirelessly to obtain and prepare a glovebox-based puncture test capability.

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4. S-TAR-F-00003, "Evaluate the physical properties of the hole indicator device that was used during the puncture incident in the F Canyon Warm Crane Maintenance Area (WCMA)

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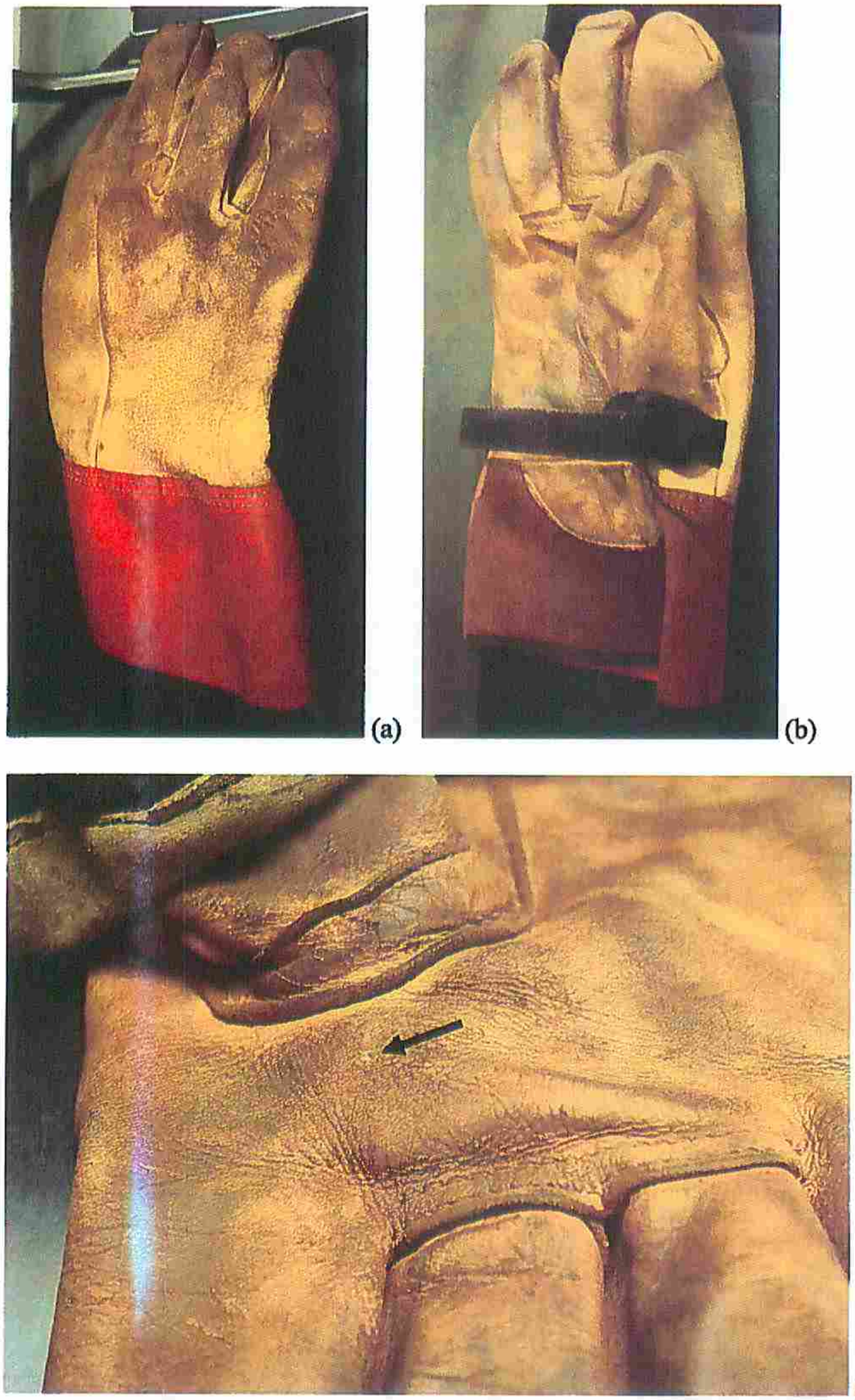
Table 1. Gamma pulse height analysis results for as-received glove (triple-bagged)

	dpm	Ci	Ci/g	mg	Percentage
Pu-238	5.58E+09	0.002514	17.1	0.146989	99.68%
Am-241	1.11E+07	0.000005	3.426	0.001459	0.20%
Pu-239	6.76E+06	3.05E-06	6.13E-02	0.049674	0.12%
Cs-137	1.01E+04	4.55E-09	87	5.23E-08	0.00%
total	5.60E+09				100.00%

Figure 1. New Salisbury LP-3S leather overglove



(a) (b) (c)

Figure 2. Punctured overglove received for examination (a, b) with detail of puncture location in palm (at arrow) (c)

(a)

(b)

Figure 3. Stereo micrographs of puncture, exterior surface, originally taken at 5X (a) and 25X (b)

(a)

(b)

Figure 4. Stereo micrographs of puncture, interior surface, originally taken at 5X (a) and 25X (b)

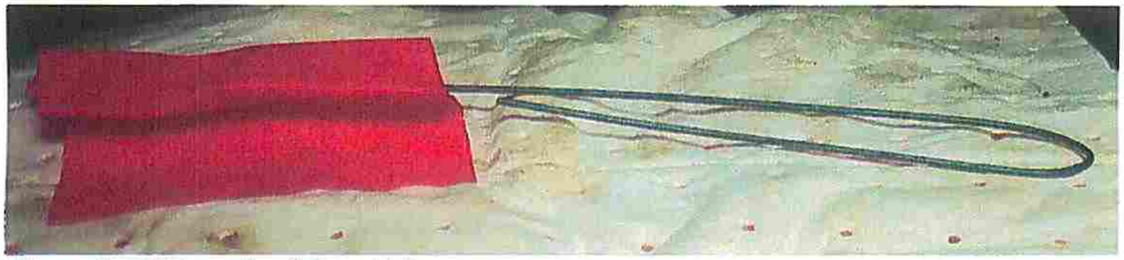


Figure 5. HID received from F Area

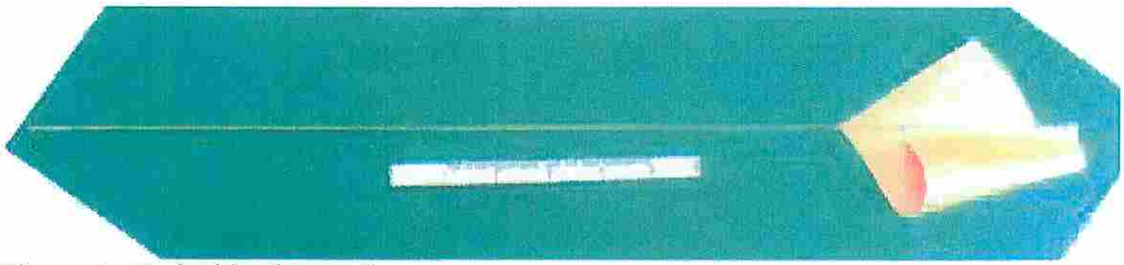


Figure 6. Typical landscape flag

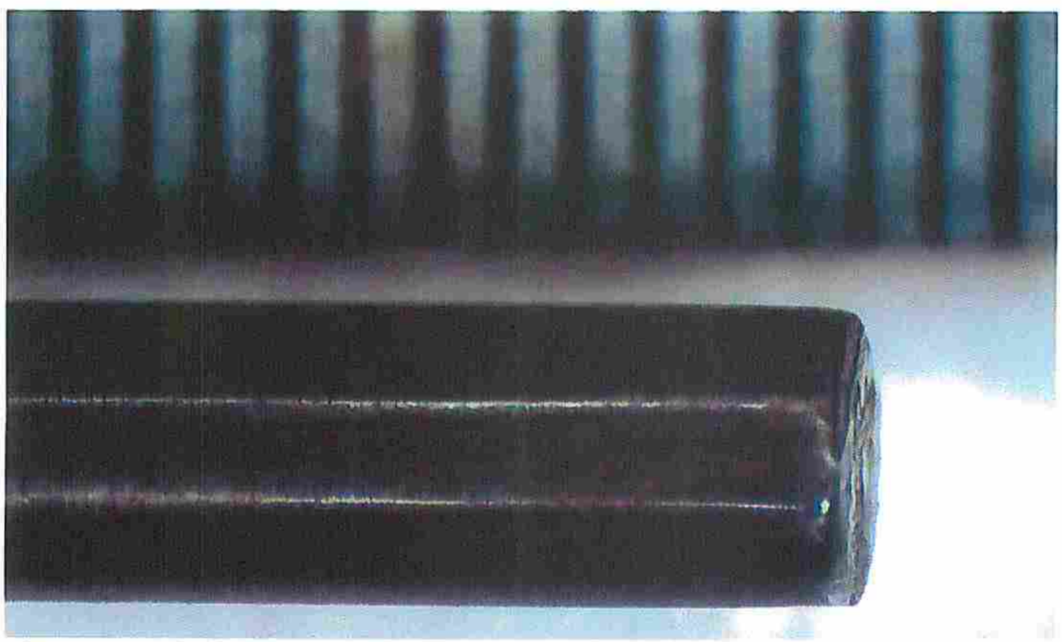
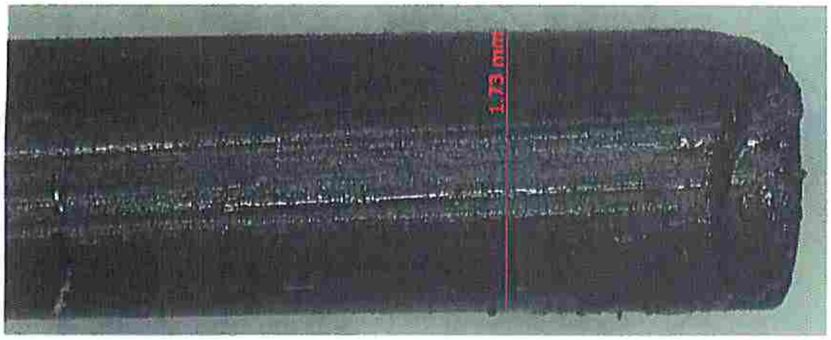
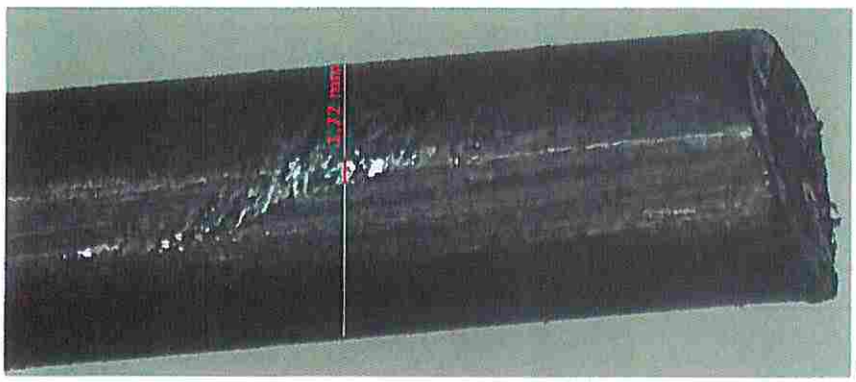


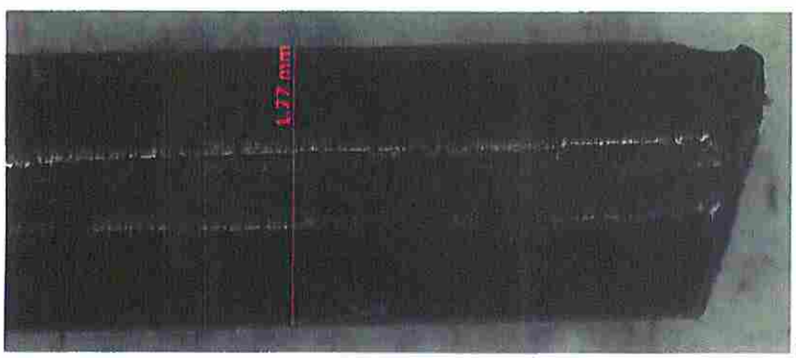
Figure 7. End of typical landscape flag, showing flat surface square to the wire axis. Approximate size 0.066 inch diameter, scale marks 1/64" apart.



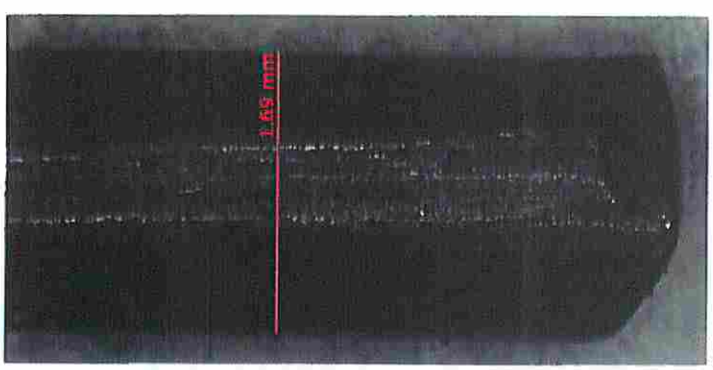
(a) 0 degrees



(b) ~90 degrees



(c) ~180 degrees



(d) ~270 degrees

Figure 8. Thickness measurements of HID, at 4 locations near tip ~90 degrees apart. The slight angle on the end of the wire is best noted in (c).

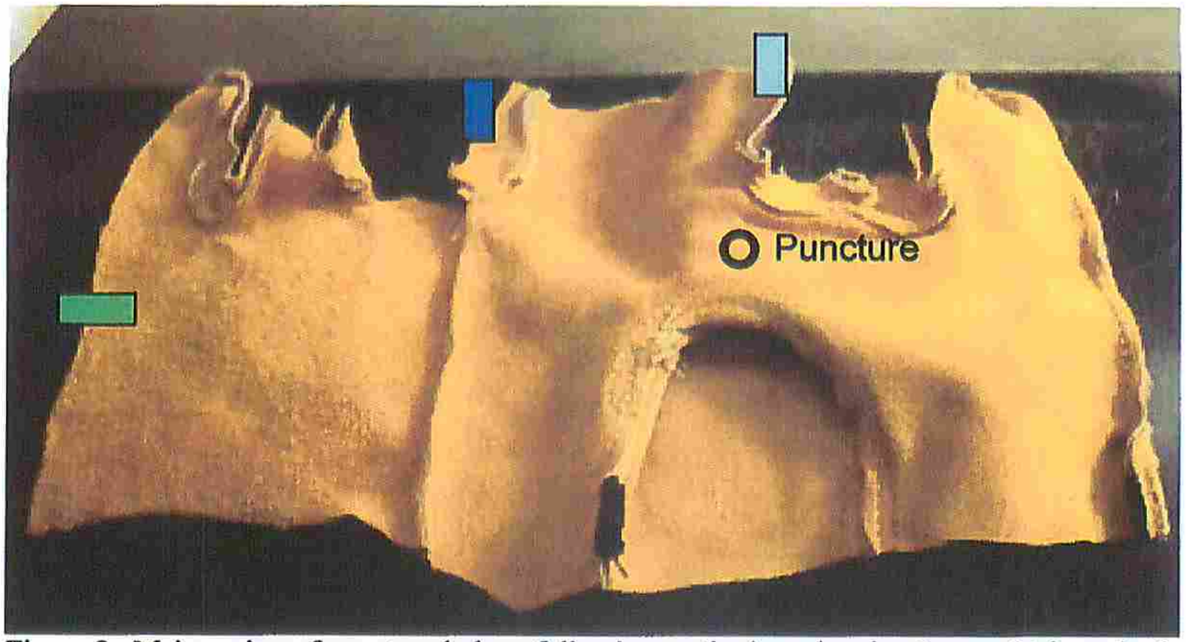


Figure 9. Main region of punctured glove following sectioning, showing 3 areas (at boxes) where the thickness was measured.

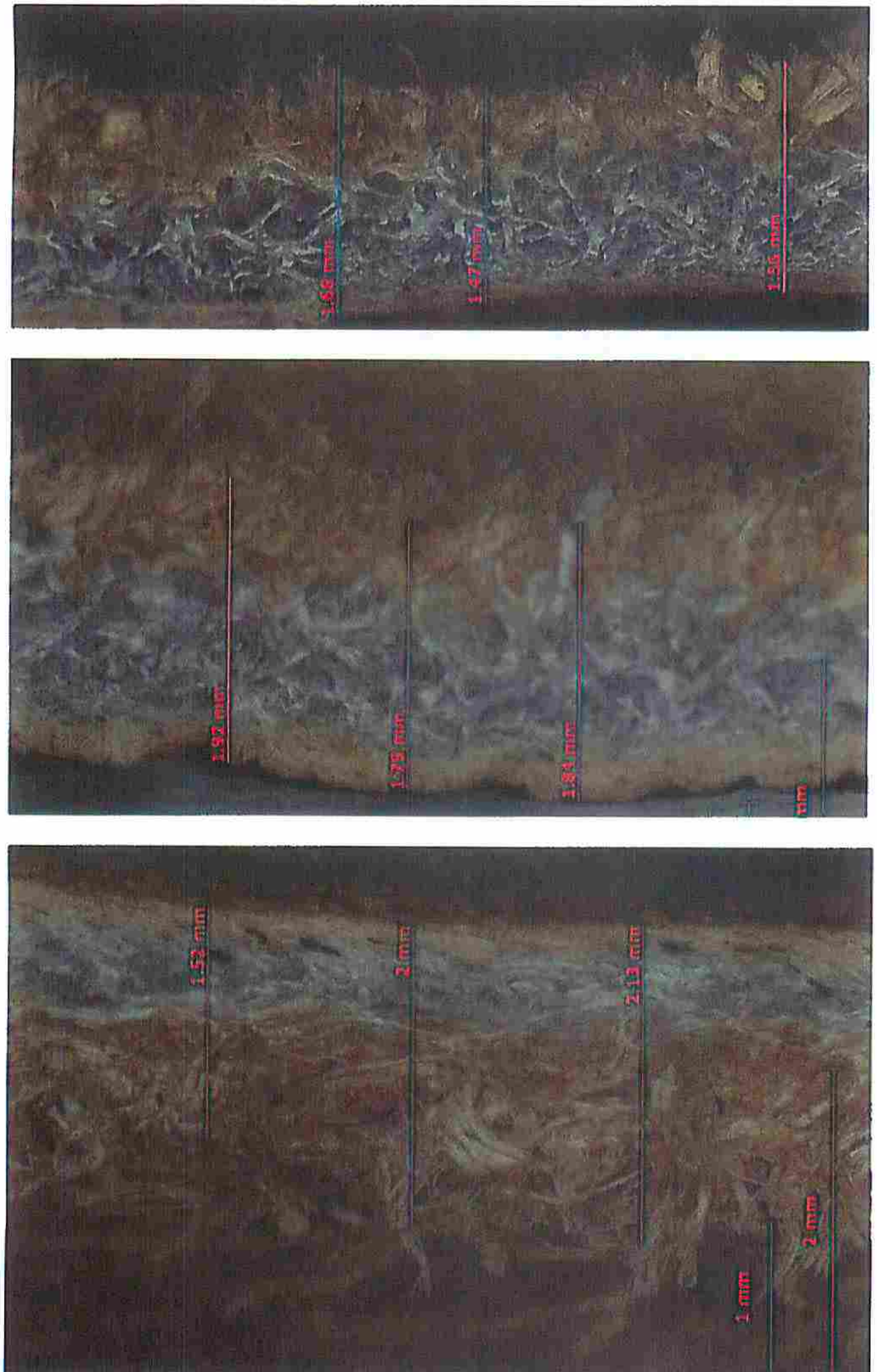
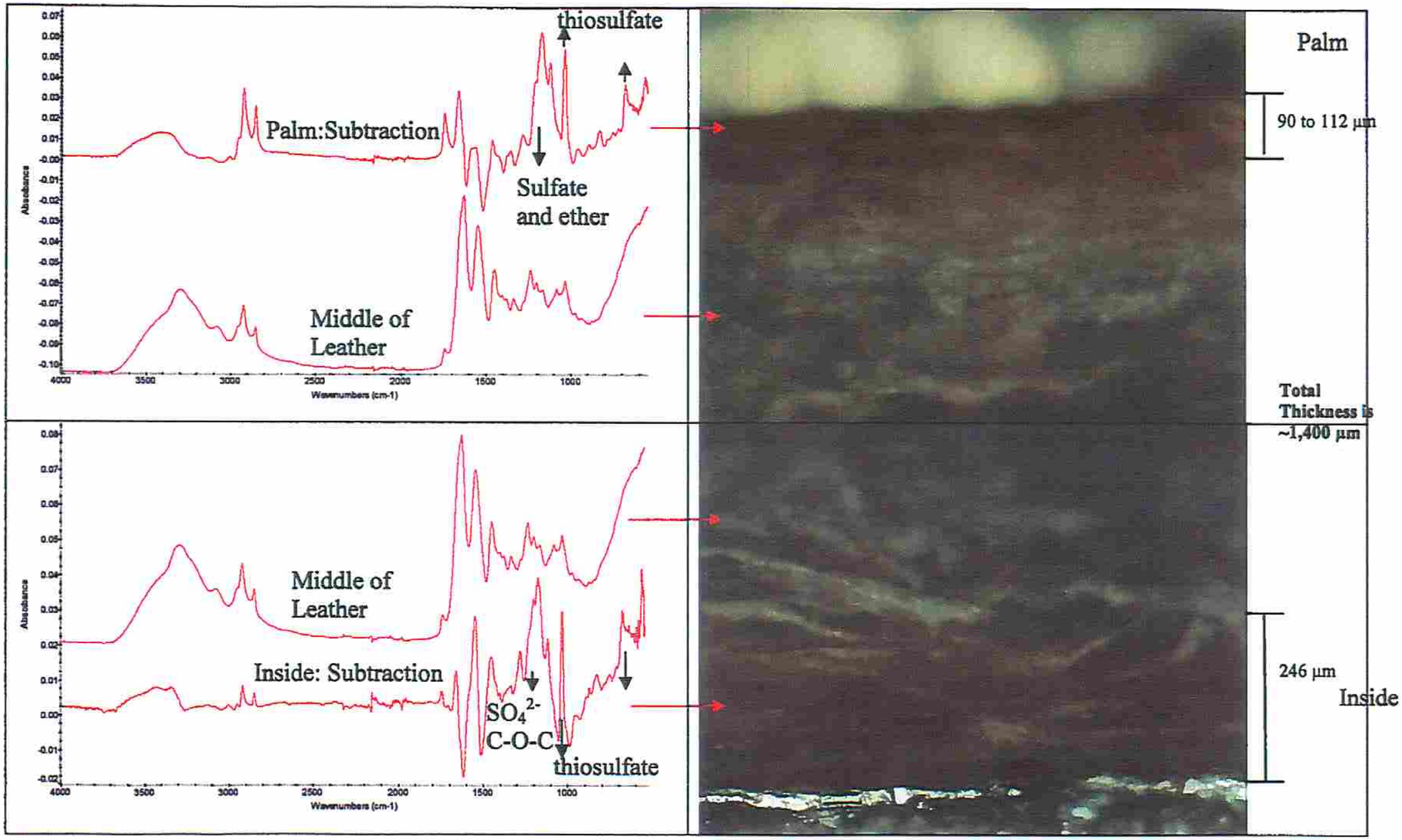


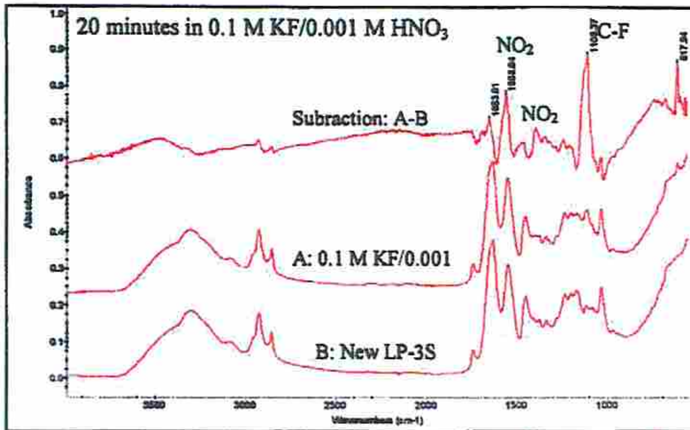
Figure 10. Glove thickness measurements performed at 3 locations around the cut edge of the punctured glove

Figure 11. FTIR Analysis of a New LP-3S Leather Glove



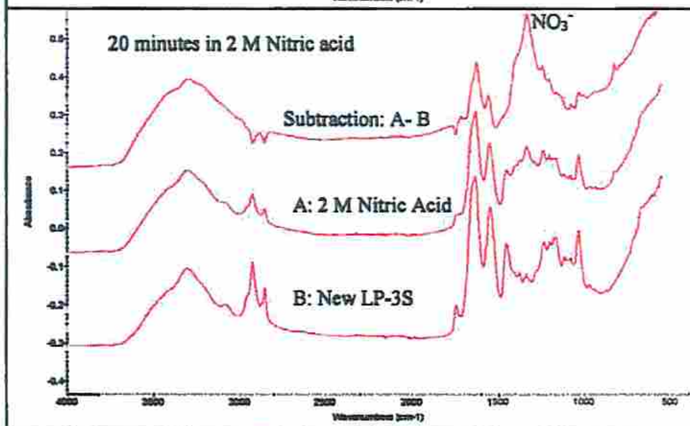
A through-thickness picture of a new leather glove (LP-3S) showing a trilayer structure (due to chemical treatment).

Figure 12. Chemical degradation: exposure to (a) combined nitric (0.001 M) and hydrofluoric acid (0.1 M), (b) nitric acid (2 M), and (c) caustic solution (2 M).



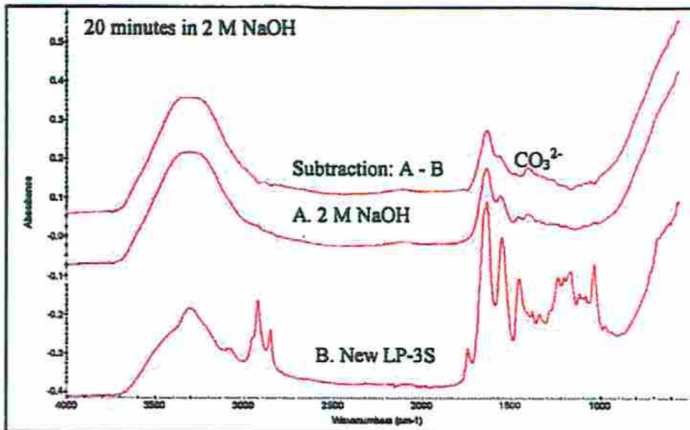
(a) Exposure to 0.001M HNO_3 / 0.1M KF

- Nitration and organofluoride formation
- Leather maintain physical integrity (shape) but swelled (~ 30%)
- Slight discoloration



(b) Exposure to 2M HNO_3

- Leather swelled by 70% (based on physical dimension measurements)
- Slight discoloration
- Nitrates (1390 cm^{-1}) and bound water is visible in the subtraction spectrum

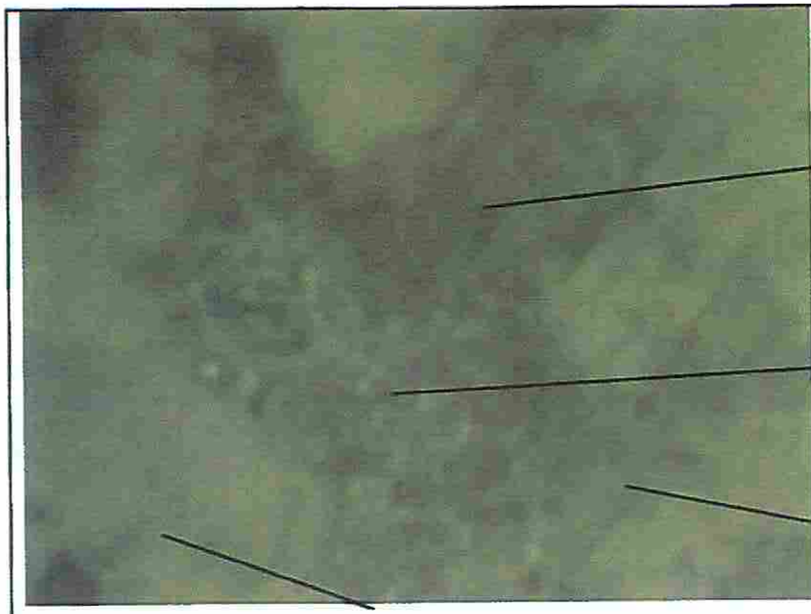


(c) Exposure to 2M NaOH

- Sample swelled to 130% and some material leached into solution
- Bound water and carbonates (1403 cm^{-1}) is seen

Figure 12 (continued)

Figure 13. FTIR Analysis of a TRU-waste containing glove



TRU waste leather glove

- Examined a 2 mm x 4 mm area
- Residues consists of a heterogeneous mixture of silica, nitrates, iron oxide and uranium oxide spread across the glove
- No yellow color on leather below the residues

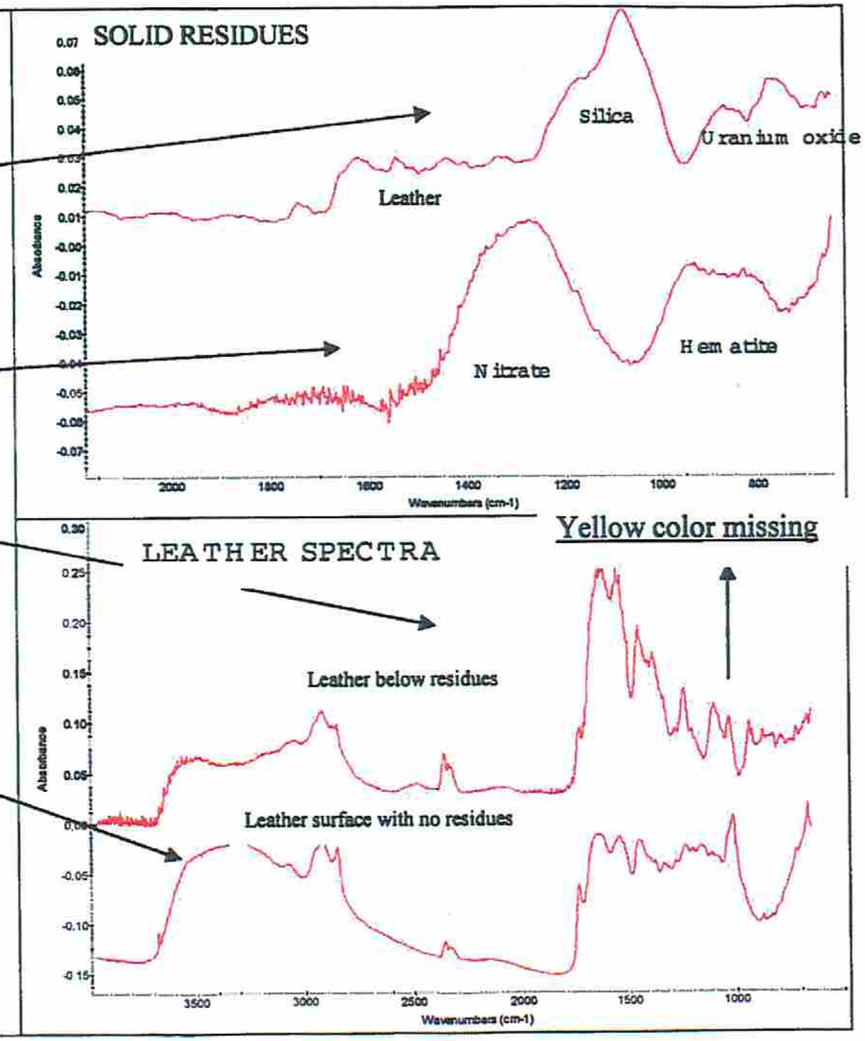
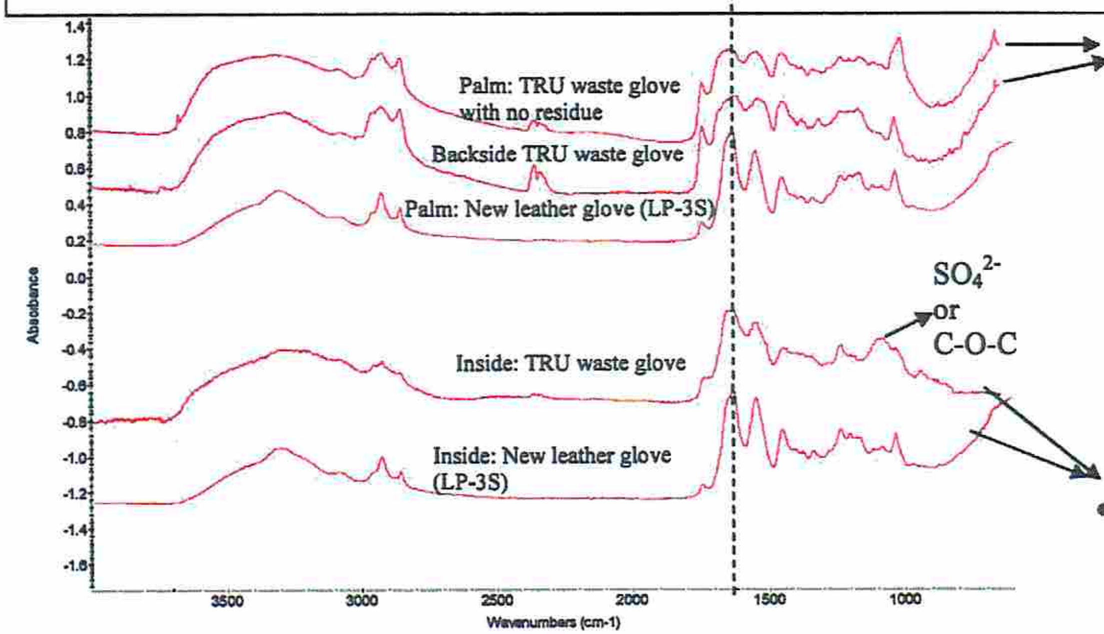


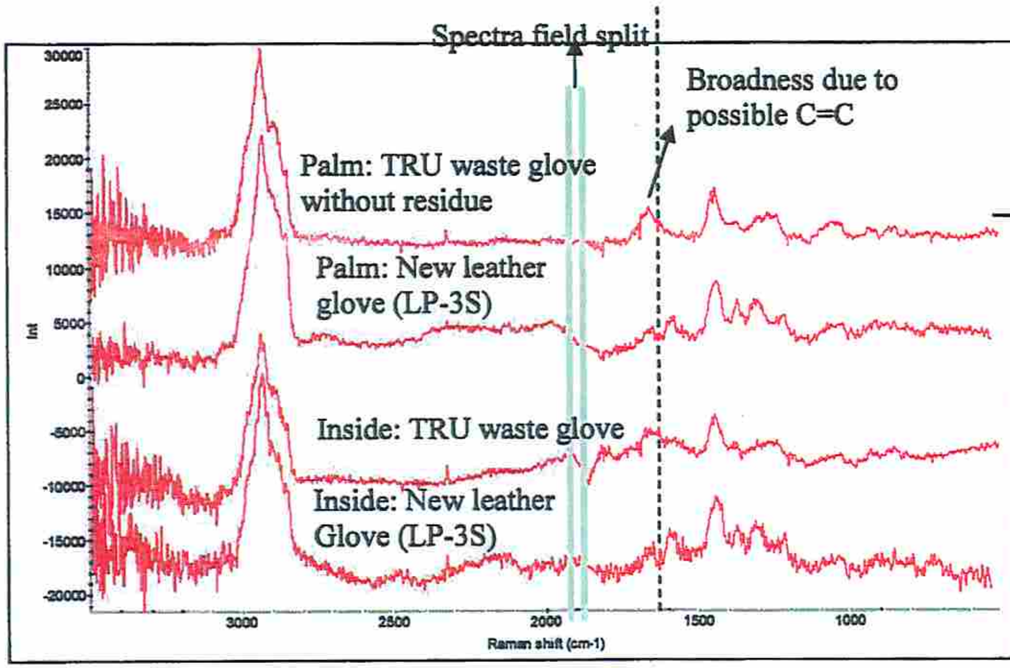
Figure 14. Comparison of the FTIR spectra from the TRU waste-containing glove and a new leather glove (LP-3S).



- Broad peaks due random texture from heavy use
- No chemical difference between the TRU waste glove (with no residues) and a new leather glove on the front or back of the gloves.

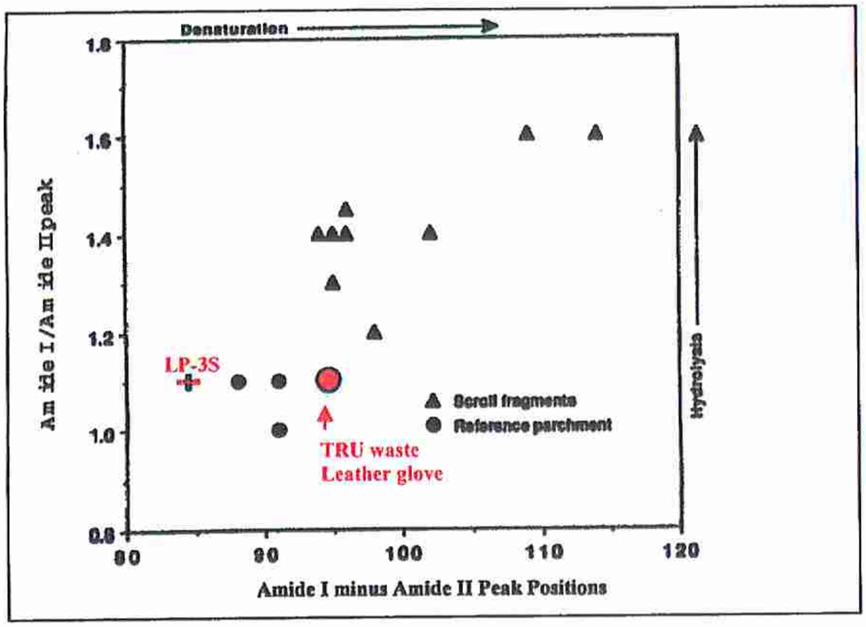
- Except for a sulfate peak in the TRU glove, no chemical differences exist between the TRU waste glove and a new leather glove.

Figure 15. FT-Raman spectra of TRU waste containing glove and a new leather glove (LP-3S).



- Peak broadening near 1667 cm^{-1} due to additional peaks associated with C=C. These peaks are small and, therefore, their amounts are small.
- No FT-Raman signal was obtained with the TRU waste containing leather glove that had residue on it as the reduced laser power did not allow penetration of the solids.

Figure 16. Deterioration as measured by changes in Amide I and Amide II peaks.



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