MINIMIZING GLOVEBOX GLOVE BREACHES: PART II

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ABSTRACT

As a matter of good business practices, a team of glovebox experts from Los Alamos National Laboratory (LANL) has been assembled to proactively investigate processes and procedures that minimize unplanned breaches in the glovebox, e.g., glove failures. A major part of this effort involves the review of glovebox glove failures that have occurred at the Plutonium Facility and at the Chemical and Metallurgy Research Facility. Information dating back to 1993 has been compiled from formal records. This data has been combined with information obtained from a baseline inventory of about 9,000 glovebox gloves. The key attributes tracked include those related to location, the glovebox glove, type and location of breaches, the worker, and the consequences resulting from breaches. This glovebox glove failure analysis yielded results in the areas of the ease of collecting this type of data, the causes of most glove failures that have occurred, the effectiveness of current controls, and recommendations to improve hazard control systems. As expected, a significant number of breaches involve high-risk operations such as grinding, hammering, using sharps (especially screwdrivers), and assembling equipment. Surprisingly, tasks such as the movement of equipment and material between gloveboxes and the opening of cans are also major contributions of breaches. Almost half the gloves fail within a year of their install date. The greatest consequence for over 90% of glovebox glove failures is alpha contamination of protective clothing. Personnel self-monitoring at the gloveboxes continues to be the most effective way of detecting glovebox glove failures. Glove failures from these tasks can be reduced through changes in procedures and the design of remote-handling apparatus. The Nuclear Materials Technology Division management uses this information to improve hazard control systems to reduce the number of unplanned breaches in the glovebox further. As a result, excursions of contaminants into the operator's breathing zone and excess exposure to the radiological sources associated with unplanned breaches in the glovebox have been minimized. In conclusion, investigations of control failures, near misses, and accidents contribute to an organization's scientific and technological excellence by providing information that can be used to increase its operational safety.

INTRODUCTION

The Nuclear Materials Technology (NMT) Division has the largest inventory of glovebox gloves at Los Alamos National Laboratory (LANL). Consequently, the minimization of unplanned breaches in the glovebox, e.g., glove failures, is a primary concern in the daily operations in NMT Division facilities, including the Plutonium Facility (PF-4) at Technical Area 55 and Chemical and Metallurgy Research (CMR) Facility at Technical Area 3. To reduce the number of unplanned breaches, a thorough understanding of the environmental and mechanical stresses that lead to a glovebox glove failure is needed. The Improving Glovebox Gloves Project (IGGP) focuses on these concerns. For a review of what has been done in the past, see the previous report in this series [Ref. 1]. In this report, progress in the areas of base-lining the glovebox glove inventory and analyzing glovebox glove failure data is presented.

A total of 707 pair of gloves were replaced in Fiscal Year 2004, with over half of them being lead-loaded Hypalon.® A more accurate breakdown is shown in Table I [Ref. 2]. The lead-loaded glovebox glove made from Hypalon continues to be the workhorse of NMT Division programmatic operations.

Table I. Glovebox Glove Usage for FY 2004

Type	Usage (Pairs)	% Usage
Hypalon 15 mil.	124	18%
Hypalon 30 mil.	131	19%
Hypalon 30 mil. Lead-Loaded	452	64%
Butasol 25 mil.	0	0%
Viton 25 mil.	0	0%
Total	707	100%

In the past, the Glovebox and Port Management System (GPMS) was used to maintain information related specifically to glove changes. Glove-change data was either recorded by the glovebox glove worker on paper and later entered into a database, or entered directly into the GPMS. Information gathered during glove-change operations through trend analysis could be used later to identify areas for improvement. Because of the difficulties in using GPMS and the lack of the value-added from entering the data into the system, buy-in from programmatic groups was not fully achieved. However, in an effort to further reduce the number of unplanned breaches in the glovebox, the gathering of glovebox glove-change data has been reimplemented. The GPMS has been given a face-lift and is now more user-friendly. The GPMS has been renamed the Glovebox Glove Integrity Program (GGIP) to reflect the broader intentions of determining the optimal schedule for changing gloves and glove types for specific working environments, and for documenting Lessons Learned from glovebox glove breaches to improve hazard control systems. Glovebox gloves in both the CMR Facility and PF-4 have been reinventoried.

The NMT Division has 683 gloveboxes, 499 in PF-4 and the remainder in the CMR Facility. The number of rooms, gloveboxes, and gloveports this entails is listed in Table II.

Table II. Glovebox Data by Facility

Parameter	PF-4	CMR Facility	Total
Rooms	43	48	91
Gloveboxes	499	184	683
Gloveports	7915	817	8732

In addition, the type of gloveboxes used may be important in determining casual factors. The types of gloveboxes used in NMT Division are listed in Table III.

Table III. Glovebox Types

Acronym	Definition
CT	Cross-Town Trolley
DB	Dropbox
EV	Evaporator
GB	Glovebox
HV	Heating and Ventilation Plenums
MP	Metal Production Line
TN	Trolley, North Side
TE	Trolley, East Side
TS	Trolley, South Side
TW	Trolley, West Side
TU	Tunnel
TT	Transfer Trolley
XB	Introductory Glovebox or Hood

The Safe Work Practices (SWPs) work control process is an essential part of Integrated Safety Management (ISM) and applies to issues of environment, safety, and health [Ref. 3]. The five-step ISM process consists of (1) defining the work, (2) identifying and evaluating the hazards, (3) developing and implementing controls, (4) performing work safely, and (5) providing feedback and continuous improvement. Adherence to SWP requirements also ensures a formal and consistent approach to hazardous operations as required by the Department of Energy order for working in a nuclear research facility [Ref. 4].

Reviewing Lessons Learned from past glovebox glove breaches to improve hazard control systems is an example of the fifth step. In this regard, glovebox glove failures that have occurred at PF-4 and the CMR Facility have been studied. Information dating back to 1993 has been compiled from formal documents that consist of Radiological Incident Reports (RIRs), Occurrence Reporting and Processing System (ORPS) Reports, Management Walk-Arounds (MWAs), and Incident Investigative Reports. This data has been combined with information obtained from the baseline inventory. The key attributes tracked include those related to location (facility, room, glovebox, gloveport), the glovebox glove (manufacturer, material, thickness, install date), type and location of breaches, the worker (organization, handedness, experience), and consequences caused by the breaches (contamination, uptake).

In the following glovebox glove failure analysis, the importance of the attributes tracked are elaborated, the results of the analysis are compiled, recommended changes to current hazard control systems are presented, issues generated from theses changes are addressed, and a conclusion is drawn from this study.

KEY ATTRIBUTES

Attributes related to location (facility, room, glovebox, and gloveport) are important to track because variables related to a programmatic task can be linked to this data. As discussed in the previous paper in this series [Ref. 1], a broad spectrum of physical, chemical, and radiological hazards are associated with the location of the glove failure. Through visual inspection of the glovebox and review of work control documents associated with it, a compilation of breach hazards can be obtained. Additional information on the use of the glove can be obtained from the tier where the glove is located. The middle tier is the working tier, where most tasks are performed. Gloves at this level are more exposed to acute physical hazards and are manipulated more. Gloves at the lower and upper tiers are of interest for aging studies because both sets of gloves are still exposed to chemical and radiological effects.

Attributes associated with the glovebox glove are also of interest. Glovebox gloves are currently being supplied by two manufactures, North Safety Products and Latex Technology Inc. (LTI). While gloves from both manufacturers meet NMT Division specifications for thickness, dimension, and shape [Ref. 5], they have very different physical properties, especially for stress[a] and strain, as shown in Figure 1.

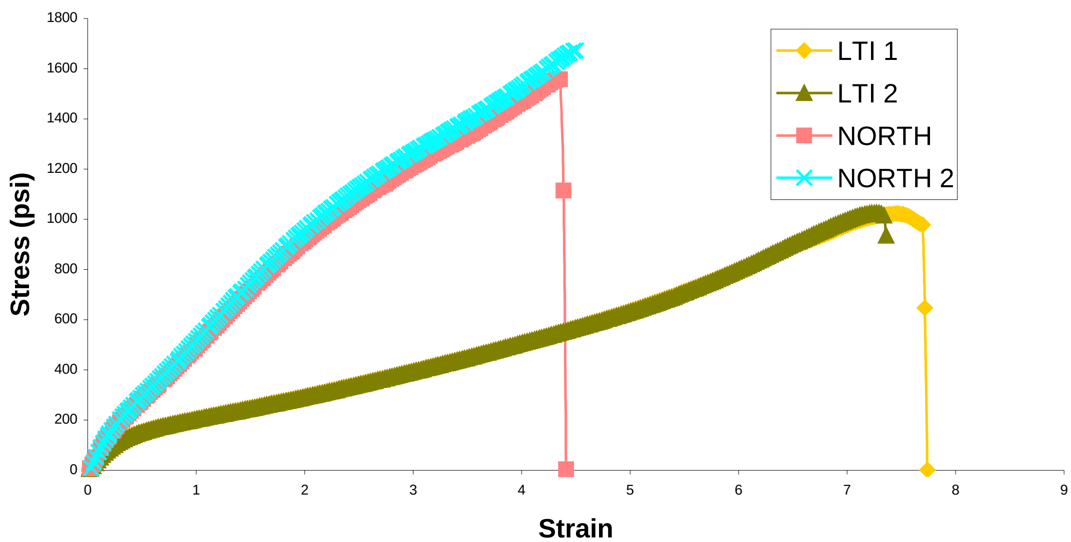

Fig. 1. Tensile Comparison—Hypalon Lead-Loaded Glovebox Gloves.

One manufacture may make gloves that are better against certain physical hazards like punctures and pinch points.

Glovebox gloves are made from four types of material: Hypalon, Hypalon with an inner lead oxide layer, Butasol,® and Viton.® Hypalon is the material of choice for most glovebox operations because it is resistant to interactions with alcohols and strong acids and bases.

Hypalon also exhibits excellent ultraviolet light and oxygen stability. Lead-lined Hypalon gloves have added radiological shielding. For gas permeability applications, Butasol is the material of choice. For operations involving bromobenzene, glovebox gloves made from Viton are selected. Correlating the materials of the gloves with the applications of each glovebox shed light on whether the gloves are being used for their recommended functions. Thicker gloves provide better protection against puncture, cut, sharps, and abrasive hazards. Thinner gloves are preferred for tasks that require more dexterity. Measuring the time intervals between when a glove is manufactured and installed may clarify whether shelf life is an important contribution to glove failures. Measuring the time intervals between when a glove is installed and when a glove fails may determine whether aging is playing a role.

Useful information can be obtained from tracking the reasons for changing gloves and the location of breaches on a glove. Glovebox gloves are routinely changed out because of *cross-contamination* and *normal wear,* and because the other glove in the glovebox was changed. Cross-contamination occurs when radioactive material is found on the inside of a glovebox glove. Typically, a contaminated inner glove is the source of contamination. Gloves are replaced because of normal wear when they appear cracked, abraded, dry rot, brittle, dirty, discolored, creased, or require change because of unacceptable beta/gamma readings.

The most common types of glove failures that occur in NMT Division operations are the following:

- **Chemical Attack**—Blistering, shredding, or shedding of layers of the glove.
- **Crack—**A fissure that appears on the surface of the glove.
- **Cut—**A slice, a smooth-edged opening in the glove caused by a sharp, smooth edged object.
- **Heat—**An opening caused by material being burned or melted by a heat source.
- **Not Determined**—No breach found even after a thorough inspection.
- **Puncture—**A pinhole, nick, or other small opening in glove.
- **Tear—**A rip, a jagged-edged opening in the glove caused by stress on the glove or by a ragged-edged sharp object, such as a saw blade.

Chemical attacks are caused by direct exposure to chemicals or vapors. If cracks and nicks are detected early enough, a breach can be avoided and the glove is changed because of normal wear. A cut, puncture, or tear may be the result of a pinching or shearing action. Normal wear has no fundamental cause other than that resulting from normal glovebox activity (or inactivity). Breaches with a cause *not determined* are most likely pinholes that escape visual detection[b] or breaches that escape visual inspection because of location.

Location of breaches provides information on ways procedures can be modified to prevent similar breaches from reoccurring. For example, if a trend is discovered where a ring finger is punctured while performing a routine task is performed a thimble may be added to the required personal protective equipment (PPE) for these types of operations. The glove locations being tracked are the upper arm, forearm, palm, finger (pointer), finger (middle), finger (ring), finger (pinkie), and thumb.

For the rare occasion when a glove failure is observed while the worker is still in the glovebox, a great opportunity presents itself. A graded approach can be taken to prevent these types of breaches from ever occurring again. Change to the hazard control system may be from a simple change in procedure (point screwdriver blades away from hand) to a new remote-handling device designed by an industrial engineer for opening cans. Tracking tasks that the worker was performing, just before the breach occurred, while less specific, is also useful.

Tracking attributes related to the glovebox worker give insight into the leadership of the organization. Also, for support organizations such as the Health Physics Operations Group, HSR-1, it gives a real-time verification of weekly preuse inspection of glovebox gloves. Because both PF-4 and the CMR Facility are owned by NMT Division, breaches caused by workers from other organizations may result from lack of training and lack of understanding of the significance of a glovebox glove failure. Data on the experience of the worker is also of interest. Answers to the following questions may be found. Which type of worker is catching the breaches in the glovebox? Are near misses, pinholes, and *not determined* breaches being caught by experienced workers or new workers? Whether breaches coupled with certain tasks always occur on the recessive (Left) or dominate (Right) hand may also be important.

When an unplanned breach occurs, the consequences include contamination to PPE (inner gloves), protective clothing (Lab coats, anti-Cs), a worker's skin, and the laboratory. An uptake of ^{239}Pu or ^{238}Pu through inhalation or injection (wound) is a much more serious consequence. This type of information is routinely captured in RIRs. Most glovebox glove failures are detected by personnel at the gloveboxes through self-monitoring, with the largest consequence being PPE and personal protective clothing contaminations. When contamination to the worker's skin or the laboratory occurs or when an uptake is reported, this incident is considered abnormal and reportable to the DOE Occurrence Reporting and Processing System (ORPS). These reports tend to be more detailed than RIRs. An abnormal event that causes major damage to a facility is called a significant abnormal event.

Dating back to 1993, information on glove changes and breaches has been entered into a database. Statistics on the data are shown in Table IV.

Table IV. Data Collected

Attributes Tracked	1228 Records Different Values	Captured Data Points	Percent Captured
Location			
Facility	2	1228	100%
Building	2	1228	100%
Room	105	1106	90%
Glovebox	219	848	69%
Gloveport	610	308	25%
Glove			
Manufacturer	2	946	77%
Material	4	814	66%
Thickness	3	814	66%
Man. Date	-	-	-
Install Date	145	625	51%
Worker			
Division	9	1082	88%
Group	21	1082	88%
Z#	194	573	47%
Handedness	2	408	33%
Date	364	1227	100%
Breach			
Type	12	1228	100%
Location	8	310	25%
Cause	91	458	37%
Task	148	239	19%

Currently, the database consists of 1228 records. Attributes discussed in the previous section are in the first column. The number of different values obtained is listed in the second column. For example, data was collected from two facilities and only two buildings. The number of data points captured per attribute varies from 100% for easily obtainable information like building number and date of the breach, to 25% for less-recorded information on breach location and the actual glovebox gloveport.

To simplify the data collection process and to maintain a consistent approach, the following protocols were carried out while gathering the information:

- If more that one breach occurred per incident, it is recorded as a separate record and breach.
- Glove changes caused by normal wear and cross-contamination are not recorded as breaches.
- If no install date was found on the glove, it was assumed to be installed in 1987.
- The old NMT-6 group information was included in the NMT-11 data.
- If no visual location of the breach is documented in a report, it is assumed that the breach location is where the contamination is located on the inner glove.
- The breach location between fingers and fingers and thumb are consisted in the palm.

Of the records collected, 56% represented glove changes from cross-contamination and normal wear. The remaining entries are documented glove failures. Because attributes related to consequence and abnormal events are only of interest with breach, they are tabulated separately in Table V.

Table V. Breach Specific Data

Attributes Tracked	545 Records	
	Data Points	Percent
Consequences		
None	37	7%
PPE	475	87%
Worker	33	6%
Lab	28	5%
Uptake	13	2%
Abnormal Events		
None	57	10%
Off-Normal	487	89%
Unusual Occurrence	1	0%

RESULTS

Glove Changes

The number of gloves changed and the reasons for the change are listed in Table VI.

Table VI. Glove Change Breakdown

Reason for Glove Change	Facility		Total
	PF-4	CM R	
Chemical Attack	2	0	2
Crack	9	0	9
Cross-Contamination	90	4	94
Cut	71	3	74
Defective glove	1	0	1
Heat	4	0	4
Normal Wear	550	30	580
Not Determined	98	1	99
Other Glove Changed	1	0	1
Pinhole	130	4	134
Puncture	51	0	51
Tear	179	0	179
Total	1186	42	1228

Most glove changes were for routine maintenance (normal wear). Cross-contamination is the second leading reason for changing gloves. As expected, the bulk of the glove changes occur in PF-4.

Before going to the focus of this analysis, which is glove failures, a few words should be said on the number of gloves changed because of near misses. Near misses are gloves that were changed before a breach occurred, or after but with no consequence. A worker will detect a nick in the glove or notice the inner layer of the glove. Sometimes, the glove feels too brittle, which is an indicator of wear. An example of nick is shown in Figure 2.

Fig. 2. An Example of Near Miss.

A total of 34 near misses were documented. Four were breaches without consequences. Three near misses were made during normal glovebox operation, with the rest detected during preinspection of the glovebox gloves. Removing all the records without a breach reduces the database to 475 entries. A representative listing of the glove failure data is discussed in the next section.

Glove Failures

Eleven rooms account for about two-thirds of the glove failures. A total of 255 gloveports accounted for almost half of all the recorded glove failures. The number of glove failures by glove material is shown in Table VII.

Table VII. Glove Failures by Glovebox Glove Type

Material	No. of Gloves	Percent of Gloves	No. of Breaches	Percent of Breaches
Polyethylene	1	0.0%	0	0.0%
Viton	12	0.1%	0	0.0%
Butasol 25 mil.	585	6.7%	56	15.7%
Hypalon 15 mil.	1249	14.3%	15	4.2%
Hypalon 30 mil.	255	2.9%	7	2.0%
Hypalon 30 mil. Lead-Loaded	6630	75.9%	279	78.2%
Total	**8732**	**100.0%**	**357**	**100.0%**

A plot of the average service life (Breach date minus the install date) of a glovebox glove is plotted in Figure 3.

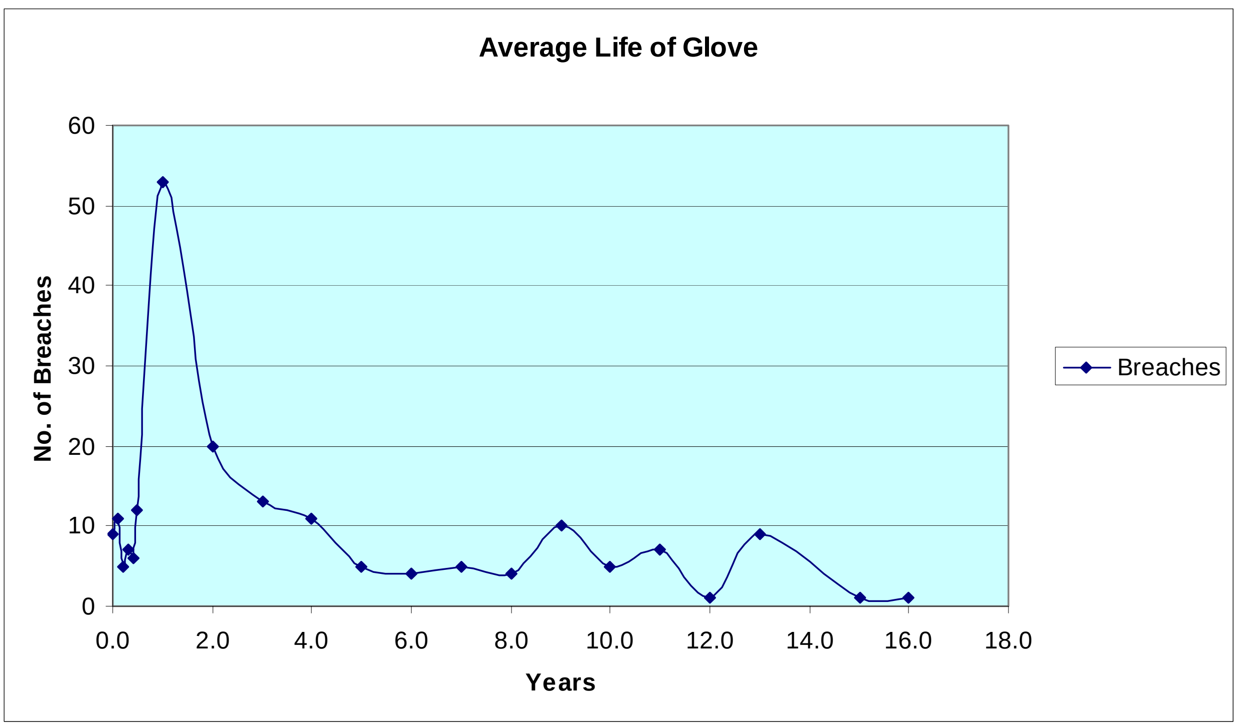

Fig. 3. Correlation of Breaches with Average Service Life of Glovebox Gloves.

Of the 342 glove failures, 160 were left-handed gloves and the remainder was right-handed gloves. The number of glove failures tracked by the breach type is shown in Table VIII.

Table VIII. Glove Failures Tracked by Breach Type

Breach Type	No. of Breaches	Percent
Tear	177	32.5%
Pinhole	134	24.6%
Not Determined	97	17.8%
Cut	73	13.4%
Puncture	50	9.2%
Normal Wear	8	1.5%
Heat	4	0.7%
Defective glove	1	0.2%
Total	**544**	**100.0%**

The number of glove failures tracked by the breach location is shown in Table IX.

Table IX. Glove Failures Tracked by Breach Location

Breach Location	No. of Breaches	Percent
Finger (pointer)	67	22.3%
Thumb	56	18.6%
Palm	53	17.6%
Forearm	51	16.9%
Upper Arm	42	14.0%
Finger (middle)	16	5.3%
Finger (pinkie)	10	3.3%
Finger (ring)	6	2.0%
Total	**301**	**100.0%**

The number of glove failures tracked by the known cause of breach is shown in Table X.

Table X. Glove Failures Tracked by Known Cause of Breach

Cause of Breach	No. of Breaches
Worker punctured glove	25
Worker pinched glove	20
Cut on the gloveport ring	12
Worker cut glove	11
Worker tore glove	8
Aging of the glove	3
Trolley related breach	3
Worker grounded a hole in glove	3
Glove tore due to a high energy release	1
Worker ripped glove apart	1
Total	**87**

DISCUSSION

This glovebox glove failure analysis yielded results in the areas of the ease of collecting this type of data, the causes of most glove failures, the effectiveness of current controls, and recommendations to improve hazard control systems. More specifically, the use of hand-held computers and user-friendly, commercially available software has greatly reduced the tediousness associated with collecting the data. As expected, a significant number of breaches involve high-risk operations, such as grinding, hammering, using sharps (especially screwdrivers), and assembling equipment. Surprisingly, tasks such as the movement of equipment and material between gloveboxes and the opening of cans are also major contributions of breaches. Almost half the gloves fail within a year of their install date. The greatest consequence for over 90% of glovebox glove failures is alpha contamination of protective clothing. Personnel self-monitoring at the gloveboxes continues to be the most effective way of detecting glovebox glove failures. Glove failures can be reduced through changes in procedures and the design of remote-handling apparatus. Gloves made of Butasol should only be used for gas-permeability applications.

The GGIP will be maintained. The goal for FY05 is to track every glovebox glove changed in NMT Division facilities. This database will lead to a more thorough understanding of the environmental and mechanical stresses that lead to a glovebox glove failure. In cooperation with a professor of Mechanical Engineering from New Mexico State University who specializes in design optimization, we propose consolidating information related to glovebox glove failures with the environmental effects that contribute to the aging of glovebox gloves, followed by a detailed statistical analysis of the collected information. Because of the complexity involved, a computer software package will be used for this research. An industrial engineer should examine this information, especially the data collected on breach type, breach location, and breach causes. We speculate that the information gathered from this effort will point to key glovebox-related attributes that are root causes of most glove failures. As a result, the transuranic and low-level radioactive waste associated with glove failures can be minimized. Not only will the results of this effort be useful for other divisions that use gloveboxes (Engineering Sciences and Applications, Material Science Technology, Chemistry), but they will also be useful throughout the DOE complex.

NMT Division generates approximately 4 m^3/yr of TRU waste from the disposal of glovebox gloves. More waste is generated when a glove failure produces a contamination incident. In addition to waste generation, significant costs are incurred from a contamination incident due to the loss in production, cost of the cleanup, and preparation of incident documentation. It has been estimated that a significant contamination incident costs in the range of $50 to $100K. Though difficult to quantify, it is estimated that successful implementation of the information gained from this analysis could reduce TRU waste by 1 m^3/yr and LLW generation by as much as 10 m^3/yr. Therefore, about $50K a year could be saved from this effort.

Collecting and analyzing data is time consuming, and the question that often arises is "Couldn't this time and effort be better spent?" This valid point should be addressed. A good analysis should include collecting data that provides meaningful output for management, health and safety experts, and industrial engineers. It is also important to understand that some attributes are important to track, but may be difficult to influence. For example, punctures caused by sharps are important to track, but no glove material has been made that is puncture-proof. Maintaining a highly trained workforce who fully understand their tasks will ensure effective performance most of the time. The real value in performance data is that it allows you to get slightly better. In addition, performance data gives you feedback on whether current hazard control plans are working. If this glovebox glove failure analysis merely confirmed what line management already knew, the analysis would have little added value. This failure analysis should provide information that would not have been discovered without the hard data. Analysis needs to provide warning signals before severely damaging problems arise.

As with all other elements of business, there are costs associated with implementing an effective "Lessons Learned" program. The main goal of an effective "Lessons Learned" program is to decrease the risk associated with this type of incident to an acceptable level. From a business viewpoint, the acceptable level may be achieved when the costs of decreasing a given risk further are greater than the costs realized from the spread of radioactive contamination. Concerning glovebox glove failures, a "Lessons Learned" program should contribute to either reducing the severity or the probability (or both) of the associated harm. With the identification of better glove materials and the appropriate replacement intervals, the number of contamination incidents and the volume of gloves disposed annually should be reduced. Thus, feedback in the form of a "Lessons Learned" program provides continuous improvement in day-to-day operations.

SUMMARY

It is the intent of this glovebox glove failure analysis for management to use this information to improve the hazard control systems used to reduce further the number of unplanned breaches in the glovebox. As a result, excursions of contaminants into the operator's breathing zone and excess exposure to radiological sources associated with unplanned breaches in the glovebox have been minimized. In conclusion, investigations of control failures, near misses, and accidents contribute to an organization's scientific and technological excellence by providing information that can be used to increase its operational safety.

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[5] Los Alamos National Laboratory, NMT-SPEC-001, Procurement of Arm-Length Dry Box Gloves Lead-Loaded Neoprene, Hypalon; NMT-SPEC-005, Procurement of Arm-Length Butyl Dry Box Gloves; and NMT-SPEC-006, Procurement of Hypalon Arm-Length Dry Box Gloves, Los Alamos, NM.

FOOTNOTES

[a] The stress is the amount of elongation divided by the original gauge length of the material.

[b] The breach is only detected because the pumping action of the gloves when in use causes a release of radioactive material from the glovebox.