MINIMIZING GLOVEBOX GLOVE FAILURES

M.E. Cournoyer, J.W. Casey, D.J. Taylor, J.J. Stimmel, R.L. Zaelke, J.J. Balkey
Nuclear Material Technology Division, Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

During the early 1990s, a series of glovebox failures caused by deterioration of glovebox gloves at the Los Alamos National Laboratory Plutonium Processing Facility were reported. As part of a proactive Lessons Learned Program, several glovebox glove failures have been reviewed. Numerous impacts in the areas of mechanical properties improvement, quality assurance, procurement, and polymer failure analysis techniques and methods have been made. The results of this effort are presented here. The main direct causes for these incidences were found to be the poor quality of the gloves received and the glovebox environment (aging). A quality program that includes access to the supplier facilities for review, audit, surveillance, witness, inspection, and/or testing activities addresses the poor quality issue. A thorough understanding of the environment and mechanical stresses to which glovebox gloves are subjected to over a glove's lifetime was needed to reduce failures. The implementation of a glovebox glove changeout program manages aging issues. Glovebox gloves must be visually checked for cuts, tears, and blisters. In addition, guidance is given to operators on whether to use leaded glovebox gloves. The selection of leaded versus nonleaded gloves is not always obvious. As Low as Reasonably Achievable (ALARA) considerations must be balanced with glove durability and worker dexterity, both of which affect the final overall risk. 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 reduced.

INTRODUCTION

Nuclear Material Technology (NMT) Division programmatic operations involve working with various amounts of plutonium and other highly-toxic, alpha-emitting materials. Extreme caution must be exercised to prevent the spread of radiological contamination. Prevention is accomplished through the use of a variety of gloveboxes. The glovebox gloves are the weakest part of this engineering control. As a matter of good business practices, the NMT Division proactively investigates processes and procedures that minimize unplanned breaches in the glovebox, e.g., glove failures. The objective of this report is to provide a sense of perspective concerning the difficulties associated with reducing the number of glove failures below their current level. To this end, the type of work that glovebox operations involve is reviewed, the hazards that can lead to a glove failure are identified, past efforts to minimize breaches are summarized, the current set of controls is discussed, and last, how future efforts will lower the number of unplanned breaches are discussed. The intent is for the reader of this document to realize that every effort short of stopping work is being done by the NMT Division to minimize glove failures.

Chemical and metallurgical operations involving plutonium and other nuclear materials in support of the U. S. Department of Energy's (DOE) nuclear weapons program account for most activities performed in gloveboxes located at NMT Division nuclear facilities. A typical glovebox train is shown in Fig. 1.

Fig. 1 Typical glovebox train.

Primary activities include the following:

- **Actinide Process Chemistry**–Provides aqueous recovery operations; pyrochemical operations converting oxides to metal; and further purification, research, and development activities to advance scientific knowledge.
- **Weapons Component Technology**–Provides pit surveillance, fabrication, assembly, and engineering services for the continual stewardship and management of the plutonium components in the nuclear weapon stockpile.
- **Plutonium-238 Science and Engineering**–Handles plutonium-238 (Pu-238) oxide, metal, and solutions in substantial quantities in unencapsulated forms.
- **Actinide and Fuel Cycle Technologies**–Focuses on the stabilization and storage of plutonium oxide materials, and the development of transmutation fuel forms.
- **Pit Disposition Science and Technology**–Dismantles the core of nuclear weapons, converts plutonium from pits into oxides, and performs nuclear fuel activities.
- **Nuclear Materials Science**–Characterizes new and aged pit construction materials and develops technologies for advanced actinide materials characterization.
- **Actinide Analytical Chemistry**–Focuses on the analysis of samples in actinide matrices, including determining the assay and isotopic composition of actinide metals and oxides, and tracing impurities in actinide samples.

Over 1200 gloveboxes with about 10,000 gloveports are used to carry out the above-mentioned programmatic activities. About 900 gloveboxes are in the Plutonium Facility (PF-4) and 300 gloveboxes are in use at the Chemistry and Metallurgy Research (CMR) Facility. About 1300 pair of gloves, with about three-quarters of them being lead-loaded hypalon, were replaced in Fiscal Year 2003. A more accurate breakdown is shown in Table I. Since 1978, North Safety had been the sole provider of glovebox gloves for NMT Division nuclear facilities. As a matter of good business practices, in 2002, Latex Technology Incorporated (LTI) was added as a supplier of glovebox gloves.

Table I Glovebox glove usage for FY 2003

Type	Cat. No.	Usage (Pairs)	% Usage
Hypalon 15 mil.	8Y15XX	129	9.4%
Hypalon 30 mil.	8Y30XX	266	19.3%
Hypalon 30 mil. Lead-Loaded	8YLY30XX	976	70.9%
Butasol 25 mil.	8B30XX	0	0.0%
Viton 25 mil.	–	6	0.4%
Total		1302	100.0%

The lead-loaded glovebox glove made from Hypalon is the workhorse of NMT Division programmatic operations. Hypalon® is a chlorosulfonated polyethylene manufactured by DuPont. Hypalon material is resistant to interactions with alcohols and strong acids and bases. This material also exhibits excellent ultraviolet light and oxygen stability. In addition, line management owning glovebox processes must make decisions on whether to use leaded glovebox gloves. Selection of leaded versus nonleaded gloves is not always obvious. As Low As Reasonably Achievable (ALARA) considerations must be balanced with glove durability and worker dexterity, both of which affect the final overall risk. Rounding out the selection of glove materials, for gas permeability applications, Butasol® is the material of choice. Last, glovebox gloves made from Viton® are selected for operations involving bromobenzene.

As expected, the operations described above encompass a broad spectrum of physical, chemical, and radiological hazards. Major hazards are listed in Table II.

Table II Hazards affecting glovebox gloves

Hazards		
Physical	**Chemical**	**Radiological**
Rotating Equipment	Hydrochloric Acid	Alpha Particles
Sand Blasting	Nitric Acid	Beta Particles
Welding Operations	Other Acids	Gamma Rays
Thermal Sources	Bases	Neutrons
Grinding	Bromobenzene	
Sharps	Gas Permeability	
Pinch Points		

Physical hazards associated with glovebox operations lead to glove failures that are primarily the result of an acute exposure. Thermal sources can cause a breach because of an acute or chronic exposure to a heat source. For the most part, chemical and radiological hazards accelerate the aging of the glove material and lead to breaches that are result of chronic exposure to the hazard.

During the early nineties, a series of glovebox failures caused by deteriorating glovebox gloves in PF-4 was reported [1]. As a corrective action, the Improving Glovebox Gloves Project (IGGP) was created to reduce radiological incidents. Since then, the IGGP has made numerous improvements in the areas of mechanical properties, quality assurance, procurement, and polymer failure analysis techniques and methodologies. This project supports ongoing Los Alamos National Laboratory (LANL) capabilities in the areas of environmental health and protection, material science, failure analysis, and direct work associated with the stockpile management programs.

To obtain a better understanding of the environmental effects that glovebox operations have on glovebox gloves and to qualify a new glove material, a material-testing laboratory in the LANL Polymers and Coating Group (MST-7) was developed [2]. ASTM International [formerly known as the American Society for Testing and Materials (ASTM] provides widely used standard material tests. Because instruments are sized such that they are amenable to being placed in a glovebox, material testing of radiologically exposed glovebox gloves is possible. Initial testing of the gloves has been performed using the standard 1-inch ball burst fixture supplied by Instron. Samples tested using this fixture usually did not burst within the travel of the test fixture, except for lead-lined Hypalon. Three fixtures were fabricated in accordance with the aforementioned ASTM standards. Results for these fixtures for several materials were reported, along with the observed rate dependence.

Highlights of the IGGP not presented in this report include the following:

- Testing and Development of New Radiological Evaluation Methodologies [3]
- The developed a real-time, puncture-detecting, self-healing material (INSTALARM) for use in glovebox gloves [4]
- Nonleaded alternatives for leaded-lined glovebox gloves [5]
- Procurement Specification for Glovebox Gloves supplied [6]

CONTROLS

To familiarize glovebox workers with glovebox gloves issues and performance in a glovebox environment, a more thorough glovebox gloves inspection program was implemented in June 2002. This training includes hands-on participation, in which workers must identify early warning signs that the glove is degrading and its performance is being compromised, such as blistering and cracking, as shown in Fig. 2.

Fig. 2 Example of a crack in a glovebox glove.

Beyond the engineering controls built into the machinery that enter the glovebox environment, the primary means of minimizing breaches associated with physical hazards is through administrative controls and PPE. For example, Hazard Control Plans (HCPs) identify sharps as a hazard in a wire-brush operation. The accompanying administrative control is to not hold the object being brushed directly with the opposite hand to the one using the wire-brush. When puncture hazards are present, thicker gloves and overgloves are recommended.

The ability to correlate changes in mechanical (physical) properties with degradation chemistry is important in gauging the acceptable standards for the polymeric glovebox gloves that are used in the laboratory environment. Towards this aim, an accelerated aging study has been performed on Hypalon and Hypalon/lead oxide-Neoprene/Hypalon tri-layered gloves to assist in determining both the shelf life and the use life of these gloves in a thermal and oxidative environment [7]. A color change associated with the aging process is observed. The appearance of the chromophore in Hypalon appears considerably before the mechanical properties of the Hypalon fall out of specifications. It was also shown in this study that the lead oxide in the tri-layered material has a dramatic effect on the difference in tensile behavior for the two materials. In contrast, the Hypalon-lead samples all demonstrate greater degradation of tensile properties under the same aging conditions. Once the onset of degradation is observed, the degradation of the mechanical properties accelerates. The presence of lead oxide contributes to or enhances the aging rate of the material.

When a glove is not in use, it is often creased or folded, and it can remain in this position for some time. Remaining in a fixed position for extended periods of time imparts a stress on the polymer, and segmental mobility of the polymer chains allows for some of these stresses to relax. This stress-imposed degradation is cumulative, and, when the glove is unfolded, there is an increased likelihood that the polymer will fail at the crease.

In effort to further reduce the number of unplanned breaches in the glovebox, a Glovebox Glove Changeout Program has been implemented. Line managers of programmatic groups were asked, "Given a certain operation, what is the average length of time a glovebox gloves was used before it was replaced?" Base on this input, recommended change intervals for glovebox gloves have been developed and implemented, as shown in Table III [8].

Table III Recommended maximum change intervals for glovebox gloves

Recommended Maximum Change Intervals					
Application	Material	Lead-Lined	Thickness (mil)	Location	Change Frequency
Pu-239 (New)	Hypalon	X	30	Lower Tier	3 years
Pu-239 (Old Pu-239/ Am-241)	Hypalon		30	Lower Tier	3 years
Pu-238 Fuel Powder	Hypalon	X	30	Lower Tier	2 years
Pu-238 Nonpowder and Dropboxes	Hypalon	X	30	Lower Tier	3 years
Acid Operations	Hypalon	X	30	Lower Tier	1 years
Gas Permeability Applications	Butasol		25	Lower Tier	2 years
Bromobenzene applications	Viton		30	Lower Tier	2 years
Glove Caps (Stub Glove + Cap)	Hypalon		30	All	5 years
Trolley Line Gloves	Hypalon		15/30	All	5 years

CURRENT ISSUES

An auditable method to track glovebox glove failures is obtained from Radiological Incidence Reports (RIRs). Recent trending analyses of RIRs indicate a gradual buildup of glove failures at TA-55. Upon further analysis, the number of glove failures is proportional to the level of effort and not caused by a systemic poor business practice. Minimal glove failures occurred during the Cerro Grande Fire standdown and the work slowdown stemming from the continuing resolution. When NMT Division nuclear facilities are fully operational, about 47 gloves fail per year.

Typical glove failure can result in worker exposure/contamination, waste generation, and work stoppage. Before work continues, the room containing the glovebox with the failed glove is usually shut down until it is cleaned up and recertified for operations. Glovebox glove failures do not usually result in radiological workers receiving a significant intake of radioactive material. Most glovebox glove failures result in alpha contamination of protective clothing, the lab worker, or the immediate laboratory area (floor).

While it is difficult to estimate the infrastructure costs associated with a glove failure, cost-benefit analysis for radiation exposure have been used to make decisions to ensure that the most cost-effective dose reduction measures are implemented [9]. Cost-benefit analyses typically apply to monetary equivalents of $1,000 to $10,000 per person-rem, with the recommended nominal value being $2,000 per person-rem. Optimization analyses are performed whenever the cost of these measures exceeds $50,000 or the collective dose to be avoided is greater that 5 person-rem; criteria that trigger an unusual occurrence.

Because of a more ergonomically favored design, the LTI-manufactured gloves *feel* thinner. This *feel* has led to the perception that LTI gloves are failing more often than the gloves supplied by North (the first supplier of glovebox gloves). Dimensional measurements prove otherwise, as shown in Table IV. Both North and LTI are much thicker than the required specification of 22 mil [6]. Except for the shoulder location, the LTI gloves are thicker than the North gloves.

Table IV Comparison of glove thickness, North versus LTI

Glove Location	North (mil)	LTI (mil)
Shoulder	31.60	29.97
Forearm	33.40	35.00
Back of Hand	36.00	38.37
Palm of Hand	31.20	37.93
Crotch of Thumb	29.00	36.57
Average Thickness	32.24	35.57
Minimal Thickness	28.00	27.00

In addition, mechanical testing of the material properties was conducted on samples of the North and LTI gloves [10]. A plot of stress versus strain as an example of each material's response when loaded to failure is shown in Fig. 3. The strain is the amount of elongation divided by the original gauge length of the material.

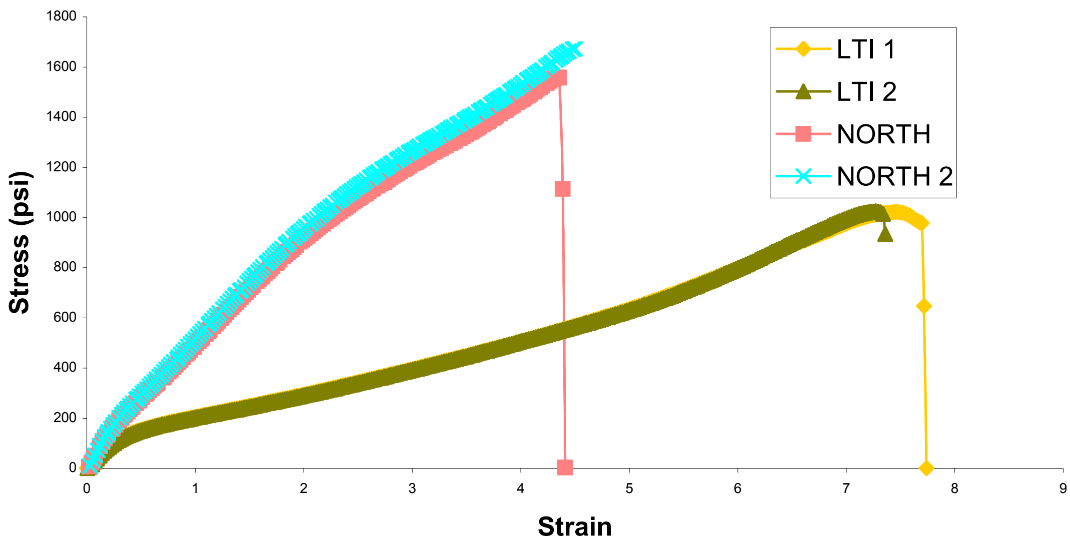

Fig. 3 Tensile comparison–Hypalon lead loaded glovebox gloves.

The data in Table V provides information about the strength of each material and its response to load. It is taken directly from the measured data provided in Fig. 3 and averaged over several samples. The most important material property to consider is the toughness, for which there is no current specification. Toughness is the integral under the engineering stress versus strain curve (those generated during tensile testing), which is the total integrated force required to take the sample from its initial unstressed state to failure. The value for toughness is more important than the value for maximum stress, because maximum stress gives no indication about the energy required to reach that maximum value.

Table V Mechanical property comparison

Property	North	LTI
Young's Modulus (psi)	786	470
50% Modulus (psi)	426	125
Max. Stress (psi)	1682	958
Max. Strain (%)	450	746
Toughness (psi)	4317	3724

As readily seen in Fig. 3, the North samples did not achieve the same elongation that LTI enjoys (~450% for North and >700% for LTI). The LTI samples also show a lower Young's modulus, 50% modulus and maximum stress. This is the primary reason the LTI gloves *feel* better (and thinner). The North gloves are stiffer, as shown by the modulus, and harder to work with. However, the overall energy absorption, or toughness, of both manufacturers' gloves is comparable.

Both manufacturers have lead-lined gloves consisting of a Neoprene® inner lead oxide layer sandwiched between two Hypalon outer surfaces. The North gloves have an advantage because the lead oxide layer is colored red, which makes potential breaches more readily detected. The LTI lead oxide layer is colored black, which makes a potential breach harder to discern in most glovebox operations. A recommendation has been forwarded to LTI suggesting a change in their process, so that the lead oxide layer is not black.

NMT Division upper management has issued a mandate to reduce unplanned breaches. From a practical point of view, this requires a better understanding of the mechanism by which the glove failed. In addition to the material testing lab, the following cost-effective, proactive approach is being taken:

1. Review all LANL RIRs related to glovebox glove failure.
2. Host a workshop specifically on glovebox gloves failures and associated experience.
3. Conduct a baseline inventory of all gloveboxes in NMT Division and record key attributes related to glovebox operations (hazards, glove material, glove manufacturers, glovebox worker, etc.).
4. Compile information on glovebox glove changes and breaches.
5. Develop a hand-held computer program to assist in obtaining this data.
6. Track information from step 1 to 4 in a commercially available, user-friendly inventory software system.
7. Analyze information gathered from this database to determine the root causes of most glove failures.
8. Modify existing work control documents to reflect *lessons learned* from this effort.
9. Maintain a database.

Typical information obtained from LANL RIRs is shown in Table VI. Note that two breaches were recorded on September 11, 2003. Information that can be tracked from a baseline inventory is listed in Table VII. Information that can be collected from the Glovebox Glove Change Form is shown in Table VIII. The fields italicized and marked in bold in both Tables VII and VIII will be scanned into the checklist using a hand-held computer equipped with a barcode reader.

Table VI Glove failure variables obtained from RIRs in PF-4

Incident ID	**Date**	**Room**	**Glovebox**	**Right or Left**	**Breech**	**Location of Breech**
03-55-4-126-1171	9/4/2003	126	GB-186	L	Tear	–
03-55-4-208-1179	9/10/2003	208	GB-231	R	Cut	Palm
03-55-4-115-1188	9/11/2003	115	–	R	–	Palm
03-55-4-115-1188	9/11/2003	115	–	L	–	Palm
03-55-4-201E-1193	9/16/2003	201E	GB-4633	R	–	Finger (pointer)
03-55-4-124-1217	9/24/2003	124	DB-119	L	Puncture	Finger (middle)
03-55-4-319-1228	10/06/03	319	GB-334	R	Puncture	Finger (middle)
03-55-4-208-1232	10/14/03	208	GB231	L	Puncture	Thumb
03-55-4-329-1255	10/28/03	329	DB-310	R	Puncture	Upper Arm

Table VII Baseline glovebox glove inventory

General Information	**Input**
Date	10/27/03
Group	NMT-X
HCP	NMT-X-HCP-001
Glovebox #	XX-399
Room #	600
Glove Port #	XX-399-01
Status	In Use
Glovebox Type:	Normal
Location	Middle (working level) Tier
Information on Glove	
Date Glove Installed	06/01/03
Recommended Change Date	06/01/06
Glove Part Number	8YLY3030
Manufacturer	North
Manufacture Date	03/01/03

Table VIII Glovebox glove change form

General Information	Input
Date	09/23/03
Glove Changer Z#	087865
Group Responsible For Glove	NMT-X
Team Leader Z#	999999
Glovebox #	XX-399
Room #	X00
Glove Port #	XX-399-01
Location	Middle Tier
Hand	Left
Glovebox Processing Environment	
SNM Type	Pu-239
SNM Form	Metal
Rotating Equipment	Yes
Sand Blasting	No
Welding Operations	No
Thermal Sources	No
Grinding	No
Sharps	No
Pinch Points	No
Other Mechanical Hazards	No
HCl Acid	No
Nitric Acid	No
Corrosives–Acid	No
Corrosives–Bases	No
Bromobenzene	No
Gas Permeability	No
Other Chemical Hazards	No
Information on Old Glove	
Date Old Glove Installed	06/01/03
Recommended Change Date	06/01/06
Glove Part Number	8YLY3030
Manufacturer	NORTH
Manufacture Date	03/01/03
Material Type	Hypalon
Lead Lined	Yes
Thickness	30
Glove Change Data	
Reason for Glove Change	Puncture
Location of Defect #1	Ring Finger
Location of Defect #2	-
Location of Defect #3	-
Location of Defect #4	-
Location of Defect #5	-

DISCUSSION

The main objective of an effective Glovebox Glove Integrity Program (GGIP) is to decrease the risk associated with a glovebox glove failure 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 excursions of contaminants into the breathing zone of the operator and the spread of radioactive contamination. Because the magnitude of a risk involves both the likelihood and the severity of the associated harm, a GGIP can be reasonably based on reducing either the severity or the likelihood, or both. It should be noted that efforts to minimized glovebox glove failures reduce only the likelihood of exposure. The severity of an unplanned breach in the glovebox remains unchanged.

The cost-benefit analyses discussed in the Current Issues section can be extrapolated to unusual occurrence triggers, loss of control of radioactive material/spread of radioactive contamination (contamination of lab), and personnel contamination (contamination on worker). In a previous paper, it was shown that about 5 off-normal occurrences associated with glovebox glove failures are reported per year [11]. Therefore, up to $250,000 a year could be expected to be dedicated to minimizing glovebox glove failures.

Environmental effects that contribute to the aging of glovebox gloves will continue to be investigated. The material testing laboratory has been moved to the University of Texas at Austin campus. With this move, radiological effects, excluding those caused by alpha particles, will be added to the list of effects studied. Later, the material testing capability will be conducted in a glovebox in PF-4 to study the effects of alpha particles on glovebox gloves. Used gloves (expired or breached) will also be analyzed. Thus, information on the combined effects that environmental and radiological stresses have on the aging of gloves will be obtained.

The database discussed in the Current Issues section will be maintained. We speculate that information gathered from this database will reduce incidents of glove failures to new lows. As an extra benefit, baseline data from glovebox operations will be used to determine the changes that aging of nuclear materials (especially Pu-239 and Pu-238) has on glovebox glove selection, leaded versus unleaded. By replacing lead-lined gloves with unleaded gloves, a significant amount of mixed waste will be avoided. Using the data from the Glovebox Glove Failure Analysis, the recommended maximum change intervals in Table II will be updated.

To reduce glovebox glove failures to the next level requires the sharing of *lessons learned* from all nuclear facilities in the DOE complex. As a next step, a Glovebox Glove Improvement Workshop sponsored by NMT Division is planned to promote sharing of expertise, experience, and lessons learned, as they relate to glovebox glove breaches, among working-level peers within the DOE complex. The workshop will target the DOE and contractor field personnel doing the actual work. The workshop agenda will include panel and poster presentations, open discussion periods, more focused concurrent sessions, and interactive poster sessions. Subject matter experts from LANL, Lawrence Livermore National Laboratory, Savannah River Site, Pacific Northwest National Laboratory, Rocky Flats, Hanford Site, Argonne National Laboratory, and Oak Ridge National Laboratory will be invited to participate.

SUMMARY

The NMT Division continues its ongoing, long-standing effort to reduce the number of glovebox glove failures. A primary objective of an effective GGIP is to minimize the risks associated with glovebox glove operations whenever possible. The efforts presented in this report represent the state of the art in reducing the number of unplanned breaches associated with glovebox operations with alpha-emitting materials. As with all other elements of business, there are costs associated with implementing an effective improvement program. Results of the glovebox glove failure analysis will be used to update the Glovebox Glove Change-Out matrix and will be shared with the rest of the DOE Complex. Last, a workshop to further reduce glovebox glove failures is being planned.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the U.S. Department of Energy and the Los Alamos National Laboratory Weapons Engineering and Manufacturing Directorate for support of this work. Special thanks is given to Carol F. Noones for editing this manuscript.

REFERENCES

1 For the most recent update, see LA-UR-03-0590, M. E. Cournoyer, and J. Dare, *An Update on the Improving Glovebox Gloves Project (IGGP)*, Lawrence Livermore National Laboratory, February 6, 2003.

2 W. P. Steckle, Jr., R .P. Mittelstet, J. M. Castro, M. E. Cournoyer, and M. E. Smith, *Puncture Evaluation of Radiological Gloves to Assess Use Performance*, American Glovebox Society Annual Conference 2002, Orlando, Florida, August 20, 2002.

3 J. Castro, J. Macdonald, W. Steckle Jr., and K. Wilson, *Light Transmission and Air Used for Inspection of Glovebox Gloves*, American Glovebox Society Annual Conference 2002, Orlando, Florida, August 20, 2002, and J. Castro, J. Macdonald, and W. Steckle Jr., *In-situ Glovebox Glove Testing*, American Glovebox Society Conference, August 2002.

4 http://www.lanl.gov/partnerships/rd100/summaries/99_execsum.html.

5 D. Dodoo-Amoo, Ph.D. Thesis, Determination of Heavy Metals and Their Leaching Characteristics in DOE Lead-Lined Gloves, University of Texas, Austin, Texas, 2002.

6 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.

7 J. M. Macdonald, A. Grand, M. Mehrafza, W. Steckle, J. Castro, D. Taylor, H. Nekimken, K. Wilson, J. Schoonover, M. Cournoyer, *Physio-Chemical Degradation of Thermally-Aged, Hypalon Glove Samples*, submitted for publication in Polymer Degradation and Stability, October, 2003.

8 NMT-AP-035, Glovebox Glove Changeout Program. Nuclear Regulatory Agency, Assessment of NRC's Dollar Per Person-Rem

9 Conversion Factor Policy, NUREG-1530, 1995.

10 M. E. Cournoyer and J. W. Casey, *Experimental Data for the Improving Glovebox Glove Project*, LA-UR-03-7335, Los Alamos National Laboratory, 2003.

11 M. E. Cournoyer and J. J. Balkey, *Minimizing Glovebox Glove Breeches*, LA-UR-03-9078, Los Alamos National Laboratory, 2003.