DEXTERITY TEST DATA CONTRIBUTE TO PROPER GLOVEBOX OVER-GLOVE USE – 10014

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ABSTRACT

Programmatic operations at the Los Alamos National Laboratory Plutonium Facility (TA-55) involve working with various amounts of plutonium and other highly toxic, alpha-emitting materials. The spread of radiological contamination on surfaces, airborne contamination, and excursions of contaminants into the operator's breathing zone are prevented through the use of a variety of gloveboxes (the glovebox, coupled with an adequate negative pressure gradient, provides primary confinement). The glovebox gloves are the weakest part of this engineering control. The Glovebox Glove Integrity Program, which controls glovebox gloves from procurement to disposal at TA-55, manages this vulnerability. A key element of this program is to consider measures that lower the overall risk of glovebox operations. Proper selection of over-gloves is one of these measures. Line management owning glovebox processes have the responsibility to approve the appropriate personal protective equipment/glovebox glove/over-glove combination. *As low as reasonably achievable* (ALARA) considerations to prevent unplanned glovebox glove openings must be balanced with glove durability and worker dexterity. In this study, the causes of unplanned glovebox glove openings, the benefits of over-glove features, the effect of over-gloves on task performance using standard dexterity tests, the pollution prevention benefits, and the recommended over-gloves for a task are presented.

INTRODUCTION

Plutonium requires a high degree of confinement and continuous control measures in nuclear research laboratories because of its very high radiotoxicity [1]. To preclude uncontrolled release, gloveboxes are used to confine plutonium during laboratory work. The glovebox is an *absolute barrier,* i.e., a sealed enclosure. The weakest link of this system is the glovebox gloves (hereafter referred to as gloves). The lead-loaded (leaded) gloves made from Hypalon® were for many decades the primary glove of choice for the Los Alamos National Laboratory Plutonium Facility (TA-55) programmatic operations and represent over 75% of the gloves used (8300 in total). Recent improvements in the Hazard Control System of glovebox operations, i.e., switching from leaded gloves to unleaded gloves, have lowered this number to 25% [2]. This has resulted in a reduction of about 3 m^3/yr of mixed transuranic (TRU) waste and low-level waste (LLW). The expectations of this improvement are reduction of injuries, increase in comfort and productivity, and a reduction of about 3 m^3/yr of mixed TRU waste and LLW. Nevertheless, incidents due to puncture wounds through a glove persist.

In January 2007, Los Alamos National Laboratory (LANL) experienced two events involving glovebox gloves that resulted in internal contamination due to puncture wounds [3]. On January 8, 2007, an employee in the Chemical and Metallurgy Research Facility (CMR), performing an operation inside a glovebox, used a screwdriver to remove a piece of material while preparing a metallographic sample. The material suddenly gave way and the screwdriver punctured a glove, an unplanned glove opening (UGO), injuring the worker's left index finger. On January 17, 2008, a TA-55 technician machining a component on a lathe inside a glovebox cut his wrist through a glovebox glove when one of his arms struck a machine tool while donning cotton over-gloves.[1]

A Type B-like investigation team was appointed and an investigation conducted. A review of the processes in place as of September 25, 2008, and feedback during the interviews conducted as part of this investigation, demonstrated that the corrective actions developed from the January 2007 events were effectively implemented and have reduced the potential for puncture wounds [4]. Then on August 13, 2008, a glovebox technician performing a machining task in a glovebox at TA-55 received a puncture wound injury through a glovebox glove that resulted in a measurable dose from internal exposure to plutonium (^{239}Pu). The machinist was using a nibbler to cut and size a stainless-steel sample when a jagged spur that was generated during the operation penetrated his over-glove (Tillman leather 24CL welding glove), glovebox glove, and personal protective equipment (PPE) consisting of a cotton glove and a surgeon's glove. The spur entered the pad of his right thumb, resulting in a contaminated puncture wound. The machinist was transported to LANL Occupational Medicine, where a wound count was reported at 83 nanocuries (nCi) of plutonium. A visible sliver was removed in an excision, and a count performed on the excised tissue read 153 nCi on the NaI detector. The machinist subsequently underwent wound decontamination and chelation treatment sessions. On April 14, 2009, the results of the official dose report became available and indicated that the technician received 1.8 rem Committed Effective Dose and 60 rem to the bone surface [5]. The operation involved in this event has been suspended since the event occurred.

One of the Lessons Learned from these events is that management should critically evaluate each hazard and provide more effective measures to prevent personnel injury.
A work release process was implemented for PF-4 gloveboxes involving shard production after the nibbler puncture/uptake event [6]. This requirement was expanded in January 2009 to cover metal cutting, machining, and handling of hard materials.
All processes at TA-55, involving metal cutting, machining, and shards production/ handling, were evaluated, hazards were identified, and enhanced controls were implemented. Improvements include use of hand tools to handle sharp-edged materials and the use of special cut- and puncture-resistant over-gloves.

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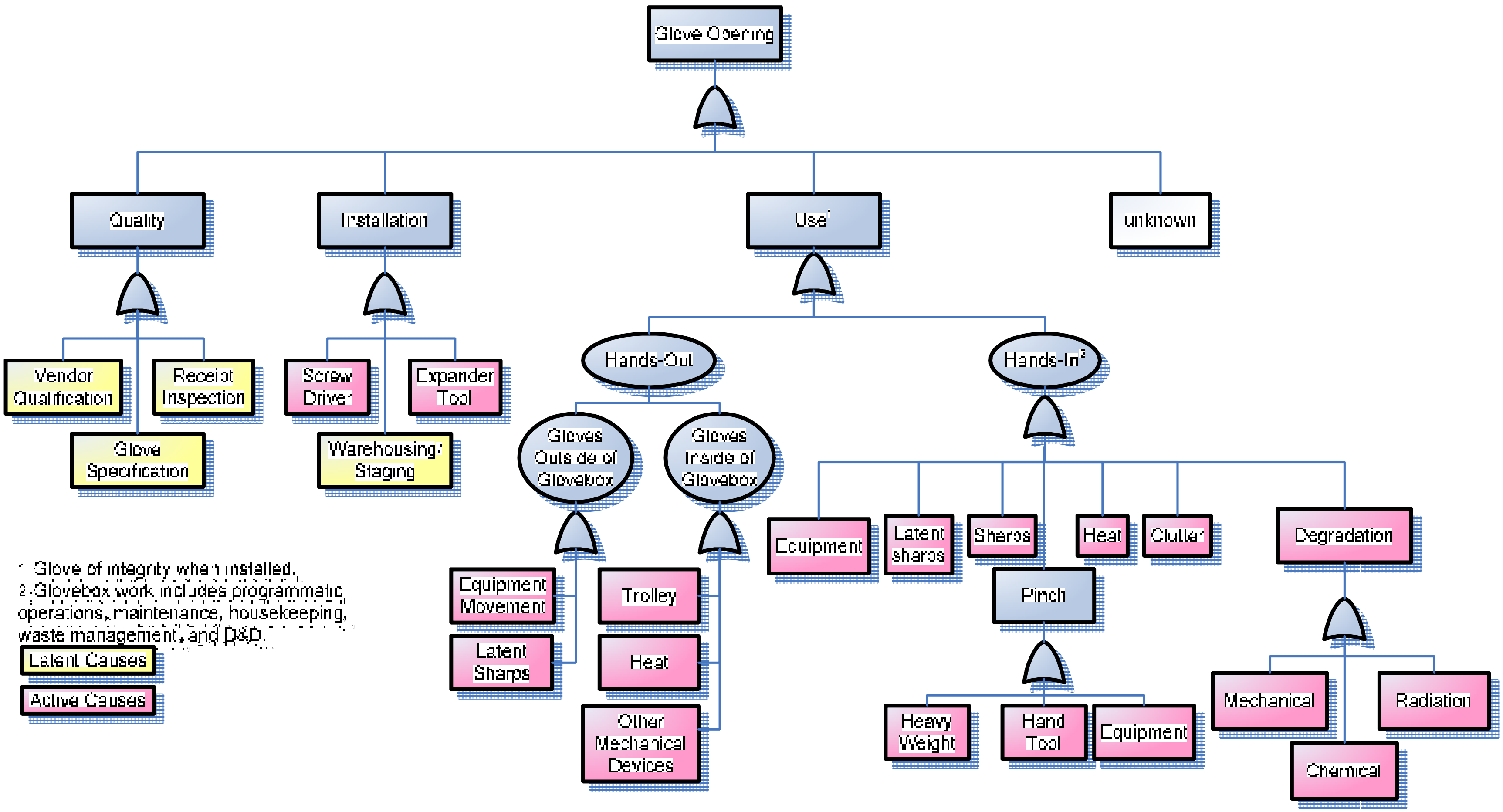
[1] Cotton over-gloves are used for quality purposes only.

Through an integrated approach, controls have been developed and implemented that come from input from glovebox workers, scientists, health physicists, statisticians, trainers, and physical therapists. Working together, this team has developed an efficient Glovebox Glove Integrity Program (GGIP). Recent accomplishments of this team have been previously reported [7]. The proper selection of over-gloves is one of the measures considered by the GGIP to prevent and mitigate personnel injuries. The three major risks from glovebox operations come from ergonomic injuries, extremity doses, and uptakes due to UGOs. When a measure is proposed to improve the Hazard Control System of glovebox operations, these three risk factors must be considered.

To help mitigate glovebox operation injuries, the science of ergonomics has been integrated into the GGIP [2]. Most off-the-shelf hand gloves are not designed to fit over the glovebox gloves. Working with glove manufacturers, oversized leather gloves and Hexarmor over-gloves are now available for use in TA-55 for operations. Efforts aimed at reducing glovebox operation injuries sometimes clash with new safety procedures, e.g., wearing over-gloves may give the glovebox worker more protection against a puncture, but also increases the risk of ergonomic injury. Studies to determine exactly how glovebox operations with and without over-gloves may affect the outcome of any dexterity task would be fundamental. Line managers and Health Physics Operations could make better decisions on which glove/over-glove combination is better suited for an operation if they knew how much longer a task takes in over-gloves versus unprotected gloves. Using the Minnesota Dexterity Test, an acceptable dexterity test, this data can be obtained. In this study, the causes of unplanned glovebox glove openings, the benefits of over-glove features, the effect of over-gloves on task performance using standard dexterity tests, the pollution prevention benefits, and the recommended over-gloves for a task are presented.

CAUSES OF UNPLANNED GLOVEBOX GLOVE OPENINGS

Based on data collection from glove change forms, a fault tree was constructed to identify causes for UGOs to prevent them to the degree practicable, as shown in Figure 1 [8].



[1] Glove of integrity when installed.

[2] Glovebox work includes programmatic operations, maintenance, housekeeping, waste management, and D&D.

Figure 1. Fault Tree Analysis of Glove Openings.

Any UGOs could cause area or personnel contamination. UGOs with hands-in-glove are of greater concern, given the higher likelihood of personnel contamination. Of the greatest concern are unplanned glove openings with hands-in-glove involving sharps and latent sharps. These can cut or puncture the skin, resulting in radioactive uptakes by workers. Definitions of various UGO causes are listed in Table I.

Table I. Definitions of Various Glove Opening Causes

Conditions		Causes	Definition
Hands-Out	Gloves Out	Equipment Movement	Openings resulted from moving equipment in the aisle coming in contact with gloves outside of the glovebox
		Latent Sharps	Openings from routine use of glove, resulting in glove catching on protrusions outside of glovebox
	Gloves In	Trolley	Openings resulted from trolley catching the gloves
		Other Mechanical Devices	Openings resulted from unintended contact with gloves
		Heat	Openings resulted from exposure to high temperature
Hands-In	Equipment		Openings resulted from contacts with equipment, e.g., knobs, edges, etc.
	Latent Sharps		Opening resulted from use of tools or materials not intended for cutting or puncture, e.g., screwdrivers, lathes, broken glass, ceramic pieces, broken crucibles, etc.
	Sharps		Openings resulted from "a thin cutting edge or a fine point; well adapted for cutting or piercing," e.g., knives, scissors, ice pick, drill bit, etc.
	Heat		Openings resulted from exposure to high temperature
	Pinch	Hand Tools	Openings resulted from use of hand tools, e.g., pipe wrench, vise grip, etc.
		Equipment	Openings resulted from use of machines and stationary tools
		Heavy Weights	Openings resulted from gloves being crushed
Degradation		Mechanical	Opening of gloves due to mechanical wear
		Chemical	Opening of gloves due to exposure to chemicals
		Radiation	Opening of gloves due to exposure to radiation

Corrective actions developed due to the two puncture/uptake events (one at the CMR and one at TA-55) in January 2007 focused on controls of sharps and housekeeping for glovebox operations. Analysis of the causes for UGOs documented from June 2006 to October 2009 indicated that these corrective actions have been effective in reducing the occurrences of UGOs due to sharps and lack of housekeeping, as shown in Figure 2.

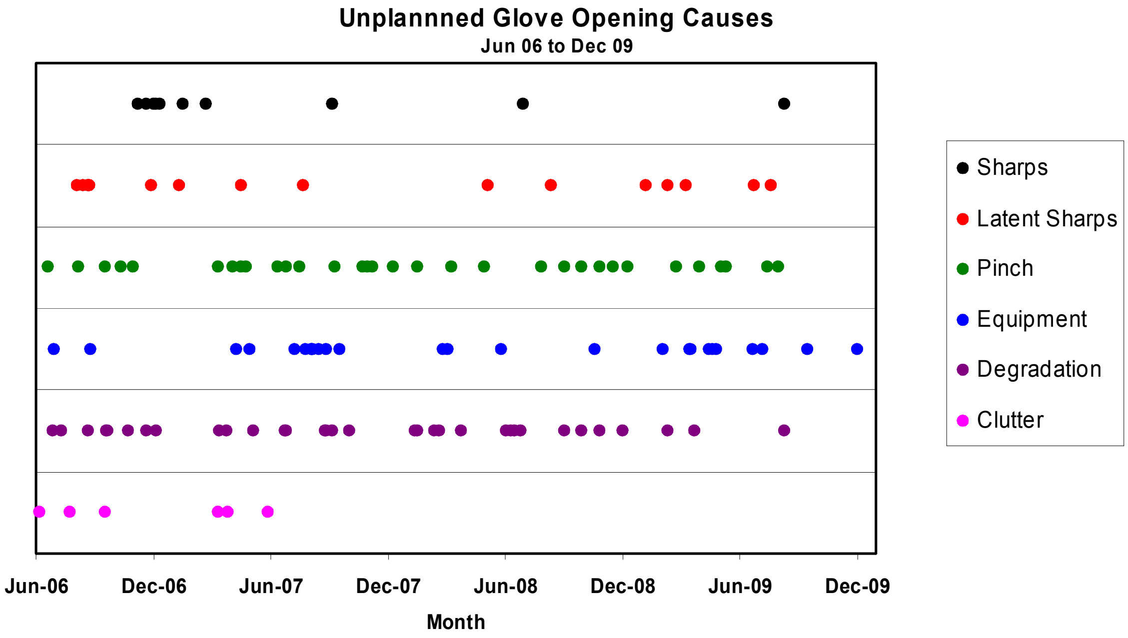


Figure 2. Unplanned Glove Openings (UGOs) Causes.

Latent sharps were also identified as a major cause of UGOs. The nibbler puncture/ uptake event in August 2008 was caused by an unobservable stainless steer sliver, a latent sharp. Other causes such as pinch, equipment, and degradation can lead to UGOs; however, the probability for puncture/uptake is much lower than that for sharps, latent sharps, or lack of housekeeping. As discussed earlier, after the August 2008 nibbler event, TA-55 management implemented a work release process for all glovebox operations involving cutting and machining of metal. After a glass shard UGO event in January 2009, this work release process was expanded to include all shard-producing operations. In the work release process, the radiation protection and industrial safety experts walk down the proposed process with the responsible managers to review all potential hazards (use of sharp tools and production of latent sharps) and proposed controls for mitigation. Analysis of causes of UGOs resulting from latent sharps, pinches, equipment, and degradation indicated that additional measures are needed to further reduce the rate of UGOs. The proper selection of over-gloves is one of these measures. Use of appropriate over-gloves, as one element of engineering controls, has been emphasized to reduce unplanned glove openings. LANL has been working with glove manufacturers to provide over-gloves that are more puncture-resistant and at the same time acceptable ergonomically.

The addition of over-gloves to protect gloves is beneficial in the prevention of UGOs because they provide a layer of defense against all hands-in tasks and degradation due to mechanical wear. Over-gloves investigated in this report should be considered when the following hazards are present: sharps, latent sharps, contact with equipment, pinch points, degradation due to mechanical wear, and clutter. Thus, the features of over-gloves that are of interest comprise protection against wear, cuts, tears, and punctures. The seven off-the-shelf gloves selected for this study are shown in Figure 3.

Figure 3. Over-Gloves Selected for This Study
Counterclockwise starting at the top left corner: Tillman Leather 24CL welding glove (Tillman Leather), TurtleSkin FullCoverage Natural Plus Gloves (Turtle Skin Plain), Northflex Duro Task Plus NFK14 (Kevlar), TurtleSkin SevereGear™ (Turtle Skin Black Palm), Piercan U.S.A. HOG0408 SF (HexArmor Short Finger), PIERCAN U.S.A. HOG0408 (HexArmor), and North by Honeywell SNI 07/497 Leather Protectors (Leather Protectors).

Their pertinent UGO prevention features are compiled in Table II.

Table II. Over-Glove Unplanned Glove Opening (UGO) Prevention Features

EN 388 Mechanical Ratings	Tillman Leather*	Turtle Skin Plain	Turtle Skin Black Palm	Kevlar	Leather Protector*	HexArmor	HexArmor Short Finger
Abrasion (cycles)	-	2	4	2	-	4	4
Cut (number)	-	2	4	4	-	5	5
Tear (newton)	-	3	2	4	-	3	3
Puncture (newton)	-	2	2	3	-	3	3

*Not EN 388 rated.

Leather gloves (Tillman Leather and Leather Protectors) are more flexible, therefore providing greater dexterity than Over-Gloves made of Turtle Skin, Kevlar, or HexArmor. While all gloves selected provide adequate protection against wear and pinch points, over-gloves made of Turtle Skin, Kevlar, and HexArmor provide additional protection against cuts and punctures.

EXPERIMENTAL DESIGN

The purpose of this study was to examine the effects of over-gloves on gross motor dexterity, with consideration of experience as a glovebox worker. To this end, a laboratory experimental design was developed.

Participants

In accordance with 45 CFR 46, *Protection of Human Subjects*, and LANL's *Federal-Wide Assurance with the Office for Human Research Protection,* Department of Health and Human Services, FWA#00000362, 62 participants volunteered to participate in this study. No tracking or numbering system links the participant to the raw data that were collected. The researchers distributing the test are the only ones who have access to the raw data.

Minnesota Dexterity Test

The Minnesota Dexterity Test was used to simulate finger dexterity and hand motions. This widely used test measures the capacity for simple but rapid eye-hand-finger movement and gross motor dexterity. This is particularly applicable in shop occupations requiring quick movement in handling simple tools and production materials without differentiating size and shape. The complete test consists of 5 different tests; however, in our study we felt that the Two-Handed Turning tests best suited the goal of the study. The scores are based on the total time required to complete an entire task. The platform consisted of tasks that used both hands together.

Glovebox Gloves

Gloves used were North by Honeywell Hypalon 0.8 mm (8Y3032). All gloves were used as received from North by Honeywell (Clover, SC).

Over-Gloves

The following commercially available hand protection was used as over-gloves: Tillman Leather 24CL welding glove (Tillman Leather), TurtleSkin FullCoverage Natural Plus Gloves (Turtle Skin Plain), TurtleSkin SevereGear™ (Turtle Skin Black Palm), Northflex Duro Task Plus NFK14 (Kevlar), North by Honeywell SNI 07/497 Leather Protectors (Leather Protectors), Piercan U.S.A. HOG0408 (HexArmor), and Piercan U.S.A. HOG0408 SF (HexArmor Short Finger). All gloves were used as received.

TA-55 Cold Laboratory

The TA-55 Cold Laboratory is a fully functional glovebox train with several types of gloveboxes in a non-radiological environment.

Experimental Sessions

One practice run with the North by Honeywell Hypalon 0.8 mm gloves was conducted before recording the results of the Minnesota Dexterity Test. All tests were performed in a random sequence to minimize the effect of learning.

RESULTS

Laboratory tests were performed to examine the effects of gross motor dexterity on seven different types of over-gloves. During the individual sessions, data were recorded manually on worksheets designed for data collection. The results of the Two-Handed Minnesota Dexterity Tests are shown in Table III.

Table III. Results of Two-Handed Minnesota Dexterity Tests

	Minnesota Dexterity Two-Handed Turning Test Results				
Over-Glove	**Sample Size**	**Mean (Seconds)**	**Stand. Dev.**	**Min Value**	**Max Value**
None [2]	32	131	50	72	327
Tillman Leather	30	140	45	76	248
Turtle Skin Plain	9	155	65	89	288
Turtle Skin Black Palm	38	160	52	92	319
Kevlar	38	175	55	84	342
Leather Protectors	25	175	50	107	302
HexArmor	17	239	78	150	429
HexArmor Short Finger	16	181	45	93	250

Results of the Two-Handed Minnesota Dexterity Tests with the North by Honeywell Hypalon 0.8 mm gloves have been already reported [2]. The tests with the Turtle Skin Plain gloves were stopped in the study due to tactile issues. After conducting tests with the HexArmor over-glove, we worked with glove manufacturers to redesign the over-glove so that it (the New HexArmor over-glove) was more suitable for our glovebox operations, i.e., shorter fingers.

The results of the Minnesota Dexterity Test are compared in Figure 4.

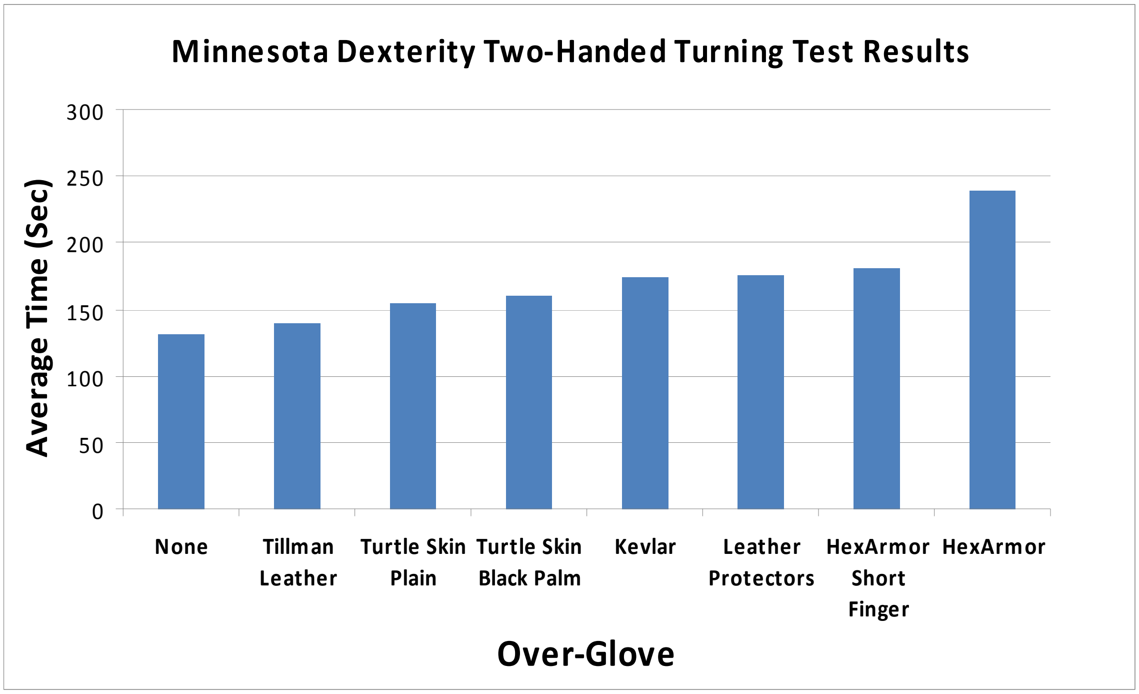


Figure 4. Comparison of Two-Handed Minnesota Dexterity Tests

Using Tillman Leather over-gloves increased the task time by about 10%, as compared to performing the test wearing only 0.8 mm Hypalon gloves. Changing the type of leather from kidskin (Tillman Leather) to cowhide (Leather Protectors) increased the task time by about 10% to 30%. Turtle Skin over-gloves were difficult to work in and increased the task time by about 20%. The decrease in performance with Kevlar, Leather Protectors, and HexArmor Short Finger over-gloves was observed to be similar. Redesigning the HexArmor significantly improved its performance.[2]

DISCUSSION

Over-gloves act as an engineering control when placed over glovebox gloves used in an abrasion, cut, tear, or puncture environment. This comes with a price. Dexterity is lost, which translates into tasks taking longer to complete, which lowers productivity, increases the likelihood of ergonomic injuries, and increases the radiation dose to the hands and internal organs. Another factor to consider is that penetrating radiation passes through tissue in a well-known manner. An uptake of plutonium into the lungs is more unpredictable [2]. Externally penetrating radiation affects cells directly, whereas *internally deposited* radionuclides must be transported through the body. Consequently, dosimetry is generally more uncertain with internal doses than with extremity doses. From a business viewpoint, the overall risk of glovebox operations would be lowered if over-gloves lowered UGOs with acceptable increases in task completion time, risk of ergonomic injuries, and radiation dose to the hands and internal organs.

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[2] The original Piercan U.S.A. HOG0408 has been discontinued, due in part to this study.

The Two-Handed Minnesota Dexterity Tests most closely simulate the type of tasks conducted at TA-55. The increase in difficulty of performing a task when adding an over-glove to a glove has been known qualitatively. The results of this study have quantified the results. The addition of over-gloves increases the performance time between 10% and 80%. The selection of overgloves took into consideration the combination of worker comfort, dexterity, and material testing. Although some of the over-gloves tested well for dexterity, workers found them uncomfortable or slippery while testing. Workers' comments were also considered in the final over-glove recommendations. The Leather Protectors, Kevlar, and HexArmor Short Finger over-gloves are not as ergonomically suitable as the Tillman Leather gloves. For specific tasks, these gloves are preferred over the Tillman Leather gloves due to their superior puncture- and cut-resistance.

Over-gloves increase waste generated in a glovebox. Field observations at TA-55 show that, for ^{239}Pu operations, over-gloves last about 1 month in the aggressive environment of the glovebox [9]. For ^{238}Pu operations, the service interval is even shorter. This increase in waste is more than offset by the number of UGOs that are prevented. Waste is generated when a UGO produces a contamination incident. For example, 23 of the 31 UGOs reported from September 2008 to November 2009 at TA-55 could have been prevented if the over-gloves presented in this study were used. At a minimum, this represents a cost savings of 23 unnecessary glove changes. Using the formula reported earlier, this equates to a cost saving of $36,000 [10]. In addition to waste generation, significant costs are incurred from a contamination incident due to the loss in production and the preparation of incident documentation. The addition of over-gloves significantly reduces the risk of UGOs with glovebox tasks associated with mechanical wear, contact with equipment, latent sharps, and pinch points. In turn, a reduction in exposure of the worker to residual contamination and a reduction in waste will be realized.

RECOMMENDATIONS

As guidance, the following controls are recommended:

- Using Tillman Leather over-gloves for tasks that involve the hazards of mechanical wear (passing tools along a glovebox line) or pinch points (using a chuck key) will eliminate UGOs with these event triggers.
- The Leather Protectors should be used for heavy wear, i.e., working in areas with latent sharps.
- The Hexarmor Short Finger gloves should be used for tasks with abrasion, cut, and puncture hazards, i.e., working with grinders, cutting tools, syringes, broken glass, etc.
- Kevlar over-gloves should be used for tear hazards such as sharps (screwdrivers) and hacksaws.
- Over-gloves should be marked with the date they are introduced into the glovebox.

CONCLUSIONS

The expectation is that the overall risk of glovebox operations will be lowered when over-gloves are used as engineering controls for tasks involving mechanical hazards. Lower UGOs come with a price: acceptable increases in task completion time, ergonomic injuries, and radiation dose to the hands and internal organs. Measures of this type improve the safety configuration of the glovebox system by lowering the overall risk in the hazard control system, including an overall reduction in waste generation, and contribute to an organization's scientific and technological excellence by increasing its operational safety.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the U.S. Department of Energy and LANL's Stockpile Manufacturing and Support; Environment, Safety, Health & Quality; and Nuclear and High Hazard Operations directorates for support of this work. Special thanks to Paula Lozar for editing this manuscript.

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