Dexterity Test Data Contribute To Reduction in Leaded Glovebox Glove Use - 9055

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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. Using an integrated approach, controls have been developed and implemented through an efficient Glovebox Glove Integrity Program. A key element of this program is to consider measures that lower the overall risk of glovebox operations. Line management who own glovebox processes through this program make decisions on which type of glovebox gloves (hereafter referred to as *gloves*), the weakest component of this safety-significant system, would perform best in these aggressive environments. *As Low as Reasonably Achievable* considerations must be balanced with glove durability and worker dexterity, both of which affect the final overall risk of the operation. In the past, lead-loaded (leaded) gloves made from Hypalon® were the primary glove for programmatic operations at TA-55. Replacing leaded gloves with unleaded gloves for certain operations would lower the overall risk as well as reduce the amount of mixed transuranic waste. This effort contributes to the Los Alamos National Laboratory Continuous Improvement Program by improving the efficiency, cost-effectiveness, and formality of glovebox operations. In this report, the pros and cons of wearing leaded gloves, the effect of leaded gloves versus unleaded gloves on task performance using standard dexterity tests, the justification for switching from leaded to unleaded gloves, and the pollution prevention benefits of this dramatic change in the glovebox system 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]. Methods and equipment must be designed toward the ultimate accomplishment of preventing any internal deposition of plutonium, even though such a degree of control may often seem extreme. Uncontrolled releases of plutonium usually result in some contamination of the atmosphere near the site of release, whether the plutonium is in a liquid, solid, or gaseous state. To preclude uncontrolled release, gloveboxes are used to confine plutonium during laboratory work. The glovebox is an *absolute barrier,* i.e., a sealed enclosure. A typical glovebox train is shown in Figure 1.

Figure 1. Typical Glovebox Train.

The weakest link of this system is the glovebox gloves (hereafter referred to as *gloves*) themselves. They are easily punctured, torn, or cracked; they will deteriorate; and they have selective permeability for various chemicals. As a matter of *As Low as Reasonably Achievable* (ALARA) and 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 openings in the gloves. Working together, they have developed the key elements of an efficient Glovebox Glove Integrity Program (GGIP). Recent accomplishments of this team have been previously reported [2]. A key element of this program is to consider measures that lower the overall risk of glovebox operations. The proper selection of gloves is one of these measures.

The lead-loaded (leaded) glove made from Hypalon® was for many decades the primary glove for the LANL Plutonium Facility (TA-55) programmatic operations and represents over 75% of the gloves used (8300 in total). Thus, studies to determine exactly how leaded versus Hypalon (unleaded) 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 is better suited for an operation if they knew how much longer a task takes in a leaded glove versus an unleaded glove. This data can be obtained by having glove workers perform acceptable dexterity tests: the Purdue Pegboard and the Minnesota Dexterity Test. In the following report, the pros and cons of wearing leaded gloves are expanded on, the effects of leaded gloves versus unleaded gloves on task performance using standard dexterity tests are examined, and the pollution prevention benefits of this dramatic change in the glovebox system are presented.

GLOVE FEATURES

Gloves used at TA-55 are made from four types of formulations: Hypalon, Hypalon with an inner lead oxide layer, Butasol,® and Viton.® Finding the most compatible glove for the glovebox environment is the key to minimizing unplanned glove openings and is the responsibility of line management. In terms of chemical compatibility, Hypalon is the material of choice for most glovebox operations because it is resistant to interactions with strong acids and bases. Lead-lined Hypalon gloves have added radiological shielding. For gas permeability applications, Butasol is the material of choice. At this time, Hypalon gloves are used for tritium operations because hazards from a breach present a greater risk than the permeation issue with tritium. For operations involving bromobenzene, gloves made from Viton are selected.

The physical and mechanical properties of the Hypalon gloves used at TA-55 are compiled in Table I.

Table I. Glove Physical and Mechanical Properties

	North Catalog No.		
Properties	8Y1532	8Y3032	8YLY3032
Material	Hypalon	Hypalon	Hypalon/Lead Oxide-Neoprene/ Hypalon
Thickness	0.4 mm	0.8 mm	0.8 mm
Tensile Strength	13.1 Mpa	13.1 Mpa	8.3 Mpa
Elongation	500%	500%	300%
Abrasion (cycles)*	1	4	4
Cut (number)*	1	1	1
Tear (newton)*	1	1	2
Puncture (newton)*	1	2	1

*EN 388 mechanical ratings for each glove.

Thicker gloves of the same material provide better protection against punctures, cuts, sharps, and abrasive hazards. Thinner gloves are preferred for tasks that require more dexterity. Tensile strength and elongation values are independent of thickness. In general, the higher the tensile strength and elongation values, the more resistant the glove is to physical hazards. The EN 388 mechanical ratings for abrasion, cut, tear, and puncture take into account the thickness of the glove [3]. The higher the EN 388 rating, the more resistant to these hazards the gloves are.

The lead in gloves is used to shield against low-energy, moderately penetrating gamma rays and x-rays (less than 50 keV), and results in a reduction of the radiation dose to the hands. The disadvantages of leaded gloves versus unleaded gloves are that a task takes longer to complete because of the reduction in dexterity, and that the glove weighs more, requiring more force to be used by the body. Furthermore, leaded gloves do little to shield against neutrons and are less effective against more penetrating gamma rays (greater than 50 keV). While leaded gloves may reduce extremity radiation doses, the lower flexibility of the leaded gloves may introduce problems for those who perform tasks requiring fine or gross manual dexterity. Additionally, prolonging the time required to perform a task may increase the total dose a worker receives. There are opportunities at TA-55 to improve overall safety for glovebox workers through better selection of gloves. Specifically, there are situations where use of unleaded rather than leaded gloves is preferable when all factors are considered. Reasons that unleaded gloves should be selected over layered Hypalon-lead gloves when possible include the following [4]:

- **Mechanical Properties:** The unleaded gloves have *significantly* better mechanical properties compared to leaded gloves, as shown in Table I. The unleaded gloves provide better protection from glove punctures. Also, the unleaded glove has a lower tear rating. Since many of the activities at TA-55 involve rotating equipment, the lower tear rating of unleaded gloves versus leaded gloves is considered an advantage.
- **Dexterity:** Unleaded gloves are more flexible, therefore providing greater dexterity than leaded gloves. The use of unleaded instead of leaded gloves is likely to result in overall greater safety from mechanical hazards. This would be particularly true and important for operations where better dexterity could provide improved safety around equipment or machinery that could cause injury or penetration of the gloves (for example, around rotating parts, sharps, or operations that require fine motor control). It would also be useful for situations in which the use of protective gloves over glovebox gloves is called for in operations that involve sharps; the loss of dexterity that results when the protective gloves are used is lessened because gloves without lead are more flexible. Like EN 388, there is a European Standard for Dexterity, EN 420 [5]. In this test, a subject wearing the test glove is instructed to pick up a series of pins of similar length but differing diameters. The dexterity is rated according to the smallest pin diameter that the subject wearing the glove can pick up; the smaller the pin diameter, the higher the rating. The EN 420 results for the gloves used in this study were not available at the time of publication.
- **Ergonomic Considerations:** Hypalon gloves are thought to be a better option from an ergonomic perspective, as they allow for more flexibility and less strain on the upper extremity. This decrease in strain to the upper extremity and back is thought to correlate with a decrease in injury, particularly injuries resulting from overuse. This issue is very significant in that glovebox workers are very susceptible to ergonomic injuries.
- **Radiation Control and ALARA:** Penetrating radiation passes through tissue in a well-known manner. The dose resulting from inhalation of airborne plutonium into the lungs is more unpredictable. 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.

EXPERIMENTAL DESIGN

The purpose of this study was to examine the effects of leaded gloves on both gross and fine motor dexterity, with consideration of gender and 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.

Dexterity Test Platforms

Two platforms were used to simulate finger dexterity and hand motions, the Minnesota Dexterity Test and the Purdue Pegboard Test. Each platform included different tasks that used the dominant hand or both hands together.

- **Minnesota Dexterity Test:** 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 Turning and One-handed Turning tests best suited what we where looking for. The scores are based on the total time required to complete an entire task.
- **Purdue Pegboard Test:** The Purdue Pegboard Test was first developed in 1948 by Joseph Tiffin, Ph.D., an Industrial Psychologist at Purdue University. The Purdue Pegboard measures the fine motor skill of an individual, taking into account single-handed dexterity as well as the use of both hands. The single-handed test, for which our subjects used the dominant hand, is a 30-second test in which the individual picks up pins and places them one by one in a row of holes provided. To measure the dexterity of both hands, the assembly test is given.

Glovebox Gloves

Glovebox gloves tested were North Hypalon 0.4 mm (8Y1532), North Hypalon 0.8 mm (8Y3032), and North Hypalon Lead-Lined, 0.8 mm (8YLY3032). All gloves were used as received from North Safety (Clover, SC).

TA-55 Cold Laboratory

The TA-55 Cold Laboratory is a fully functional glovebox train with several types of gloveboxes, including a trolley line, in a nonradiological environment. Gloves were assembled on a rigid glovebox.

Experimental Sessions

One practice run with the 15-mil gloves was conducted before recording the results of the Minnesota Dexterity Test and the Purdue Pegboard Test. All tests were performed in a random sequence to minimize the effect of learning, which could affect the results.

RESULTS

Laboratory tests were performed to examine the effects of dexterity on three different types of gloves. During the individual sessions, data were recorded manually on worksheets designed for data collection. In all, 62 TA-55 residents participated in the study. The anthropometric data for the study is compiled in Table II.

Table II. Anthropometric Data

Anthropometric Measurement	Mean	Standard Deviation	Minimum Value	Maximum Value
Worker Height (cm)	173	10	152	193
Elbow Height (cm)	107	6	90	116
Shoulder Height (cm)	142	8	126	163
Shoulder Reach (cm)	65	5	53	70
Hand Breadth (cm)	9	1	7	10
Hand Circumference (cm)	25	2	21	29
Hand Length (cm)	19	1	17	22
Finger Length (cm)	8	1	7	10

The results of the dexterity tests are shown in Tables III and IV.

Table III. Results of Minnesota Dexterity Test

	One-handed Turning Test (sec)	Turning Test (sec)	Pincer Test (kg)	Grip Test (kg)
Statistics	Hypalon 0.4 mm Thickness Glove			
Mean	95.8	88.4	6	42
Standard Deviation	19.1	20.8	2	10
Minimum Value	68.4	59.5	3	19
Maximum Value	137.1	123.0	10	57
	Hypalon 0.8 mm Thickness Glove			
Mean	119.6	111.0	6	39
Standard Deviation	18.8	37.5	2	9
Minimum Value	82.2	72.2	3	20
Maximum Value	136.8	193.3	11	51
	Hypalon 0.8 mm Thickness Lead-Loaded Glove			
Mean	152.5	123.4	6	36
Standard Deviation	35.9	28.7	2	8
Minimum Value	102.7	80.2	3	21
Maximum Value	242.0	166.2	11	50

Table IV. Results of Purdue Pegboard Dexterity Test

	Dominant Hand Test	Assembly Test	Pincer Test (kg)	Grip Test (kg)
Statistics	Hypalon 0.4 mm Thickness Glove			
Mean	8.1	9.2	6	39
Standard Deviation	1.7	2.7	1	10
Minimum Value	5.0	3.0	4	19
Maximum Value	11.0	14.0	9	54
	Hypalon 0.8 mm Thickness Glove			
Mean	5.2	4.3	7	39
Standard Deviation	2.4	2.4	2	10
Minimum Value	1.0	1.0	3	18
Maximum Value	9.0	10.0	10	61
	Hypalon 0.8 mm Thickness Lead-Loaded Glove			
Mean	4.5	4.3	6	39
Standard Deviation	1.9	2.4	1	10
Minimum Value	2.0	1.0	3	18
Maximum Value	9.0	10.0	9	61

Analysis

The analysis of the anthropometric data, and its correlation to the performance data, is beyond the scope of this paper and will be reported at a later date. The results of the Minnesota Dexterity Test are compared in Figure 2. Doubling the thickness of the Hypalon gloves (0.4 mm → 0.8 mm) increased the task time by one-fourth for both the one-handed and the two-handed tasks. As expected, tasks with the leaded gloves take significantly longer than with unleaded gloves of the same thickness (0.4 mm). For the one-handed task, the leaded gloves take about one-fourth longer. The difference is cut in half for the two-handed task.

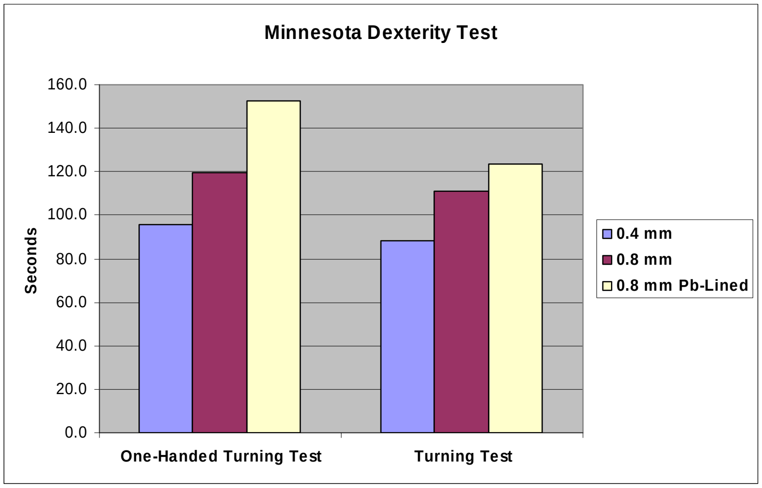

Figure 2. Results of the Minnesota Dexterity Test.

The results of the Purdue Pegboard Dexterity Test are compared in Figure 3. When the thickness of the Hypalon glove is doubled (0.4 mm → 0.8 mm), performance decreases by about 40% for both the leaded and unleaded gloves for the Dominant Hand Test and by about 50% for the Assembly Test. The performance of the unleaded glove was observed to be about 10% better than the leaded glove of the same thickness in the Dominant Hand Test.

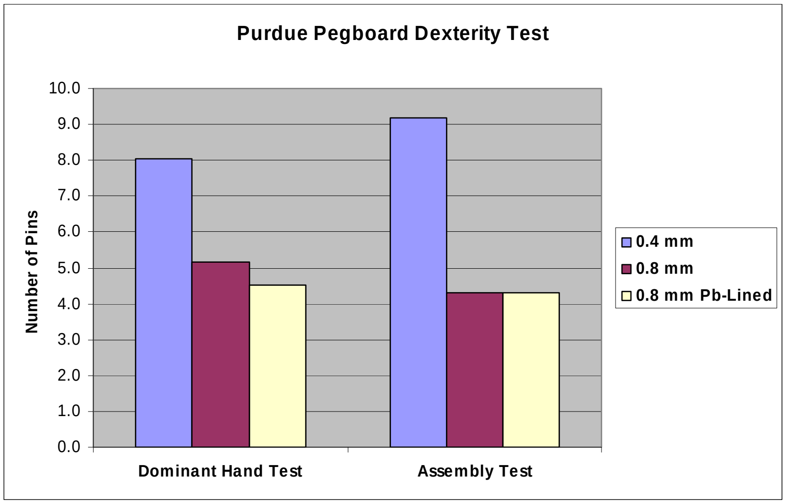

Figure 3. Results of the Purdue Pegboard Dexterity Test.

The results of the Pincer Test and Grip Test are compared in Figure 4. No difference in the pincer test was observed. A slight decrease in grip strength was observed as the thickness of the glove was increased, and then again when lead was added to the formulation.

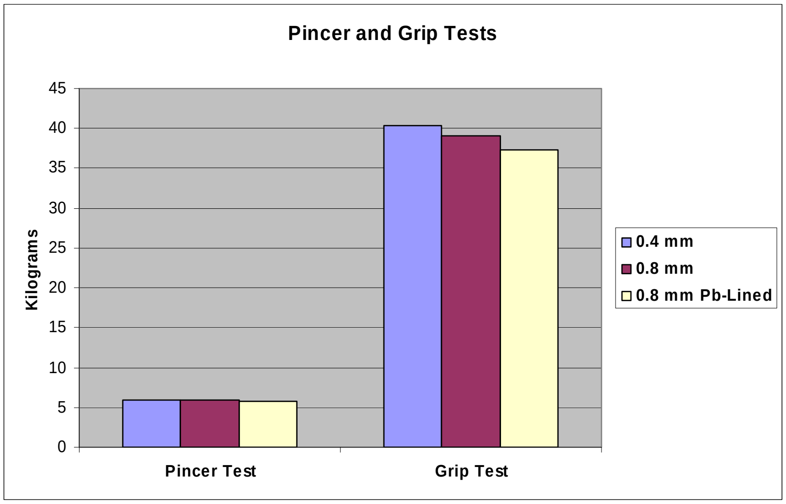

Figure 4. Results of the Pincer Test and Grip Test.

DISCUSSION

The increase in difficulty of performing a task when the thickness of a glove is increased or lead is added to the formulation has been known qualitatively. The results of this study have quantified the results. The Dominant Hand Test most closely simulates the type of tasks conducted at TA-55. For operations that require fine motor skills, the thickness of the glove is more important than whether it is leaded or unleaded. The thickness and formulation of the glove have little effect on pincer and grip tests. These tests will not be included in future studies. EN 420 dexterity results will be obtained for future glove studies and compared against the results of the Purdue Pegboard Dexterity Test. In addition to dexterity tests, anthropometric data were also collected. The correlation of anthropometric data to performance data will be reported at a later date.

A main objective of an effective GGIP is to maintain the risk of an unplanned glove opening to an acceptable level. From a business viewpoint, the acceptable level is reached when the costs of decreasing a given risk further are greater than the costs realized from radiation exposure to 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, continuous improvement of a GGIP can be reasonably based on reducing severity, likelihood, or both. Switching from leaded gloves to unleaded gloves should increase production by one-fourth for most ^{239}Pu operations. As discussed in the *Glove Features* section, fewer glove breaches due to punctures should be observed. LANL has a Continuous Improvement Program in which efficiency, cost-effectiveness, and formality of operations are constantly being improved; the program is supported by *Lean Six Sigma* activities using Lean Manufacturing and Six Sigma business practices.[1] Improvements of this nature contribute to this effort as well.

Every year, 1300 pairs of gloves are replaced at TA-55, generating about 6 m^3/yr of transuranic (TRU) waste and low-level waste (LLW) that represents an annual disposal cost of $6000. More waste is generated when a glove breach 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. By replacing leaded gloves with unleaded ones, a dramatic reduction in waste will be realized; exposure of the worker to residual contamination will be reduced; and the number of breaches would be reduced.

Leaded gloves provide greater protection against external radiation doses to the extremities and, to some degree, to the whole body, but the primary effects are in extremity dose reduction. There are some situations in which leaded gloves are needed. For example, leaded gloves should be used for operations that involve routine hands-on work with ^{238}Pu or containers with significant quantities of ^{238}Pu. Other gloves in ^{238}Pu work areas that are not routinely used for handling of ^{238}Pu do not need to be leaded (for example, upper-level gloves).

However, in making ALARA decisions, all factors are looked at, including the greater protection that is provided against accidental large internal doses that could result from a breach in a glovebox glove. With most ^{239}Pu operations, this is the case. Leaded gloves are typically *less effective* against ^{239}Pu, particularly when there is a significant amount of ^{241}Am present. Unleaded gloves are preferable in these operations because of their better overall characteristics. The default for ^{239}Pu operations should be unleaded gloves, unless it has been shown that there is a need to reduce extremity exposures for certain very *hot* operations where the annual extremity dose limit could be reached. In general, when switching from leaded to unleaded gloves, external radiation readings should be taken so that changes in radiological conditions are characterized. This must be done to ensure that the effect of the change on extremity doses is known, as well as any changes in work area dose rates.

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[1] Named after the number of standard deviations around the mean (6σ).

In summary, the use of unleaded instead of leaded gloves is likely to result in overall greater safety from mechanical hazards. This is particularly true and important for operations where better dexterity provides improved safety around equipment or machinery that causes injury or penetration of the gloves (for example, around rotating parts, sharps, or operations that require fine motor control). It is also useful for situations in which the use of protective gloves over glovebox gloves is called for in operations that involve sharps; the loss of dexterity that results when the protective gloves are used is lessened because gloves without lead are more flexible.

CONCLUSIONS

When dose to the extremities is not an issue, 0.8 mm Hypalon gloves should be used in place of 0.8 mm leaded Hypalon gloves in glovebox activities involving gross motor skills. Measures of this type improve the safety configuration of the glovebox system by lowering the overall risk in the current hazard control system, and contribute to an organization’s scientific and technological excellence by increasing its operational safety.

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