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Abstract

Ergonomic injury and radiation exposure are two safety concerns for the Plutonium Facility at Los Alamos National Laboratory (LANL). This facility employs the largest number of gloveboxes (GB) at LANL with approximately 6000 gloves installed. The current GB glove design dates back to the 1960's and is not based on true hand anatomy, revealing several issues: short fingers, inappropriate length from the wrist to finger webbing, nonexistent joint angles and incorrect thumb placement. These design flaws are directly related to elbow (lateral epicondylitis) and thumb (DeQuervain's tenosynovitis) injuries. The current design also contributes to increased wear on the glove, causing unplanned glove openings (failures) which places workers at risk of exposure. An improved glovebox glove design has three significant benefits: 1) it will reduce the risk of injury, 2) it will improve comfort and productivity, and 3) it will reduce the risk of a glovebox failures. The combination of these three benefits has estimated savings of several million dollars.

The new glove design incorporated the varied physical attributes of workers ranging from the 5th percentile female to the 95th percentile male. Anthropometric hand dimensions along with current GB worker dimensions were used to develop the most comprehensive design specifications for the new glove. Collaboration with orthopedic hand surgeons also provided major contributtions to the design. The new glovebox glove was developed and manufactured incorporating over forty dimensions producing the most comprehensive ergonomically sound design. The new design received a LANL patent (patent attorney docket No: LANS 36USD1 "Protective Glove", one of 20 highest patents awarded by the Richard P. Feynman Center for Innovation. The glove dimensions were inputed into a solid works model which was used to produce molds. The molds were then shipped to a glove manufacturer for production of the new glovebox gloves. The new glovebox gloves were tested against the presently used glovebox gloves for design validity. The testing included a subjective survey and four dexterity tests. The prototype was statistically significant in 3 dexterity tests and favorable on 8 out of 10 survey questions. The more ergonomically sound glovebox glove will improve worker comfort, mitigate glovebox worker injuries, and reduce glove breaches.

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CONTENTS

Determining the appropriate glove dimensions for the new glovebox glove utilized an in depth review of the anthropometric hand data, including the Army Anthropometric Survey of U.S. Army Personnel [16], University of Nebraska data [17], and the Air Force anthropometric data [18]. Data from a previous glove study conducted at LANL was also used as a reference. Current glovebox worker's hands were sketched; the measurements were taken to ensure correlation between the worker's hand dimensions and the anthropometric data collected. A depiction of the comparison is noted in Figure 1 for the index finger.

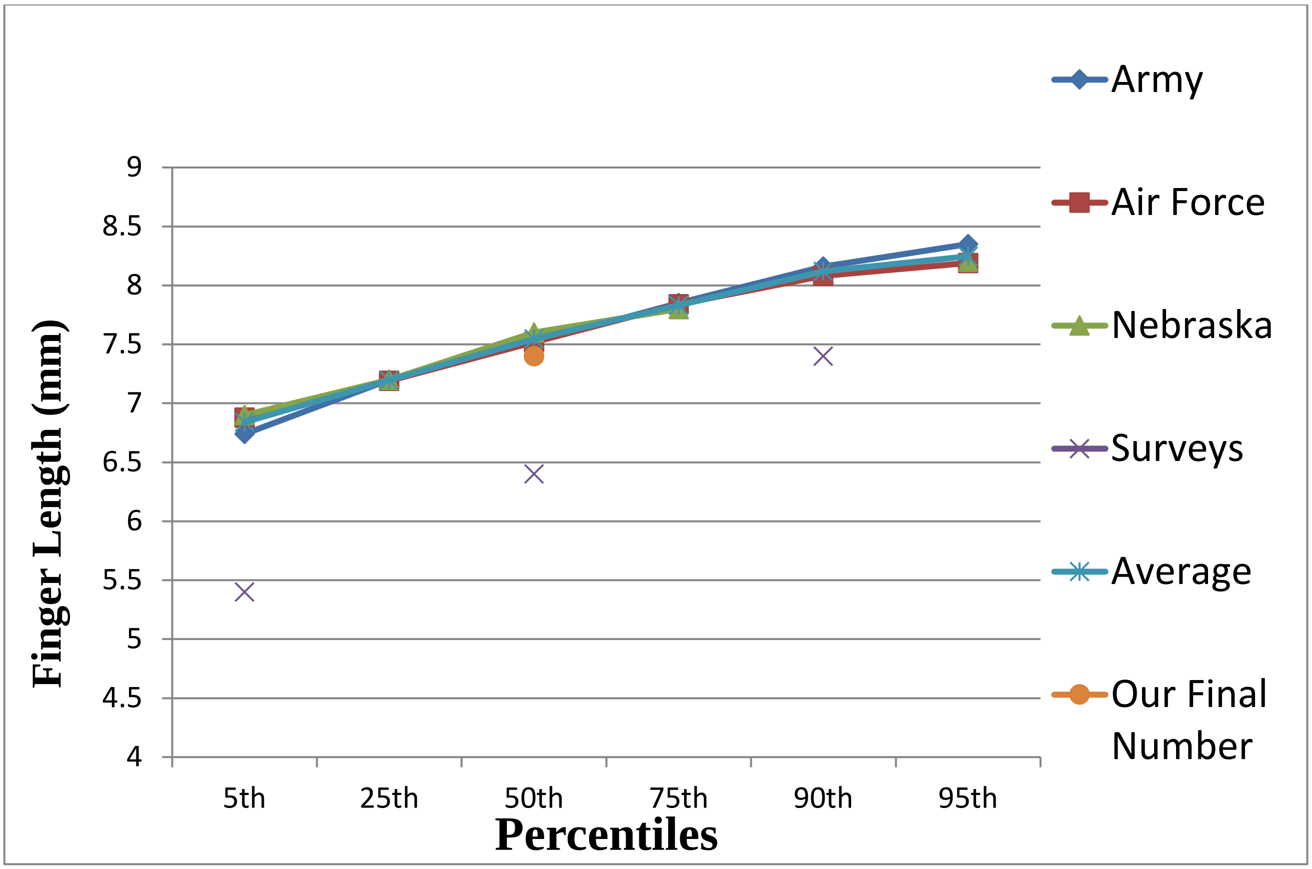


Figure 1:   Anthropometric data comparison for index finger length

Finger lengths were determined dependently. The index finger was chosen first since it is the most utilized of all fingers. The fingers must relate to all other fingers, rather than use of a percentile data for a particular finger. From the index length, the transitions from finger to finger was determined and thus gave the lengths of the subsequent fingers (Table 1). This method allowed for the appropriate relationships. Additional design criteria included: web (crotch) lengths, finger segment ratios (crotch-to-PIP joint; PIP joint-to-tip of finger), PIP joint circumferences, palm circumference and wrist circumference. (Tables 1-4 and Figures 2 -5).

Finger Lengths (cm)		Webspace-PIP (cm)	PIP-Tip (cm)
Thumb	6.8	3.3	3.5
Index	7.4	2.4	5
Middle	8.3	2.9	5.4
Ring	7.8	2.4	5.4
Pinky	6.3	1.6	4.7

Table 1: Glove finger length

Webspace-PIP-Finger Length: Ratios		
Thumb	49%	51%
Index	32%	68%
Middle	35%	65%
Ring	31%	69%
Pinky	26%	74%

Table 2: Phalange length ratios

Palm Lengths (cm)	
1	6.7
2	10.8
3	10.7
4	9.5

Table 3: Palm length

Hand Circumference (cm)	
	25.4
PIP Circumferences (cm)	
1st	8.2
2nd	8.1
3rd	8.3
4th	7.8
5th	7.1

Table 4: Hand and finger circumference

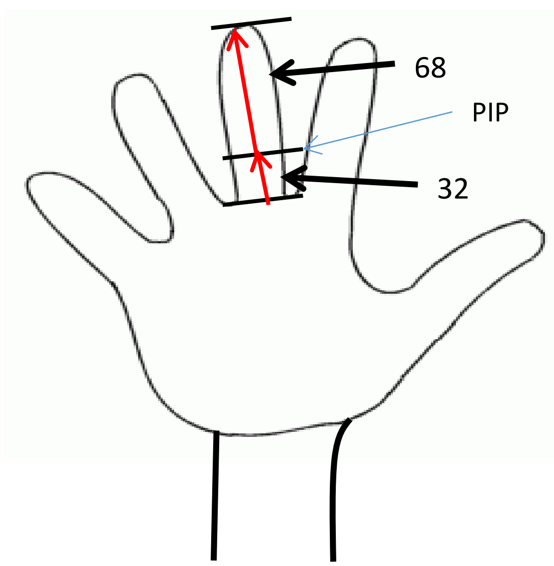


Figure 2: Depiction of phalange ratios

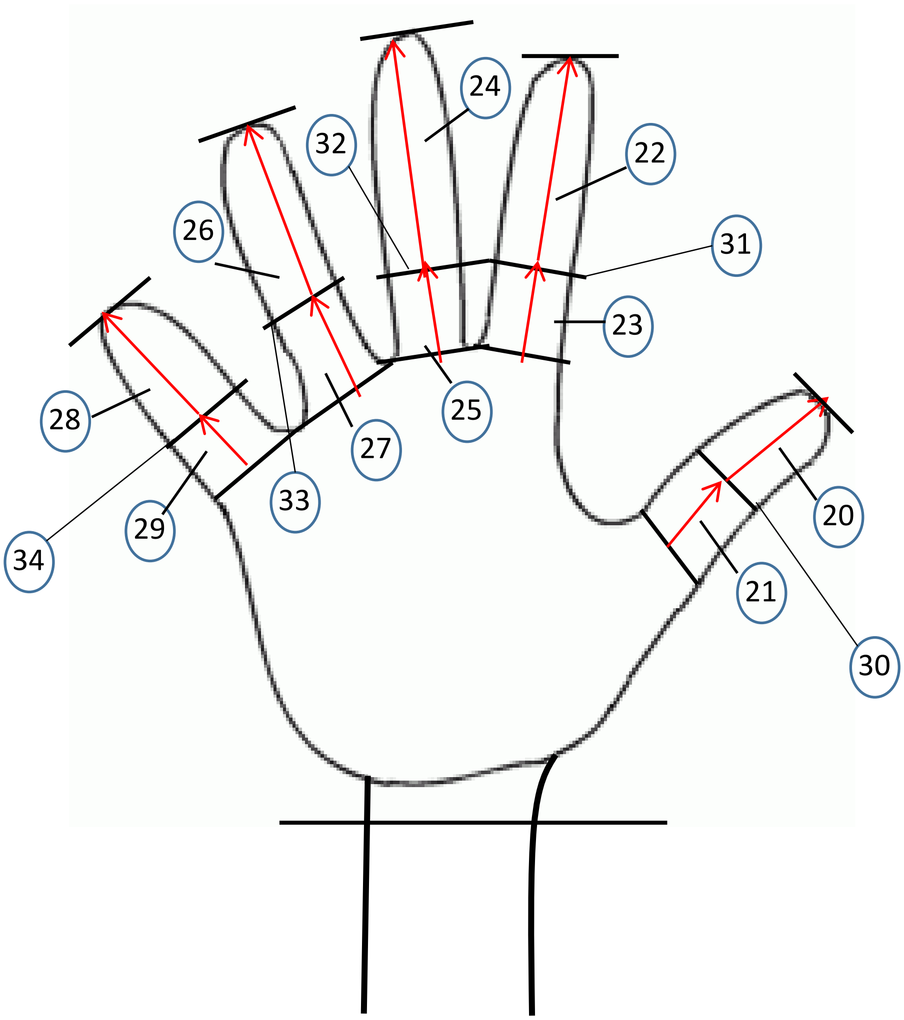
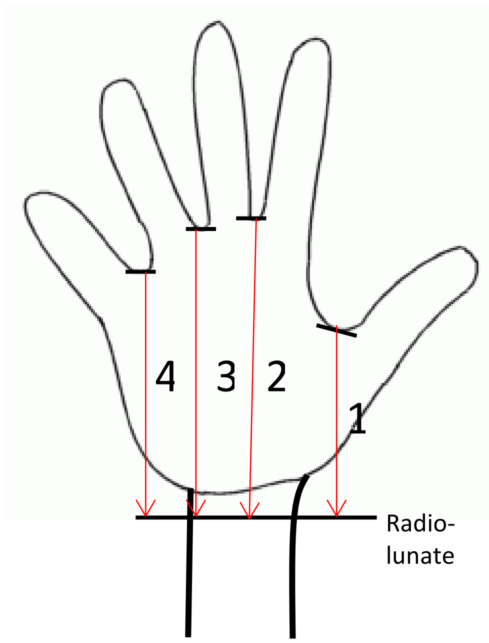


Figure 3: Summary of finger lengths dimensions

('mm)	
Thumb: PIP to Tip of finger (20)	35
Thumb: Webspace to PIP (21)	33
Index: PIP to Tip of finger (22)	50
Index: Webspace to PIP (23)	24
Middle: PIP to Tip of finger (24)	54
Middle: Webspace to PIP (25)	29
Ring: PIP to Tip of finger (26)	54
Ring: Webspace to PIP (27)	24
Little Finger: PIP to Tip of finger (28)	47
Little Finger: Webspace to PIP (29)	16
Thumb Circumference (30)	82
Index Circumference (31)	81
Middle Circumference (32)	83
Ring Circumference (33)	78
Little Finger Circumference (34)	71



1-4: Webspace length measurements (mm)

- Webspace 1 Length: 66.92
- Webspace 2 Length: 108.13
- Webspace 3 Length: 106.89
- Webspace 4 Length: 94.99

Determined by UNM
Hand length should be taken from tip of middle finger to Radiolunate of wrist

Figure 4: Web-space length measurements

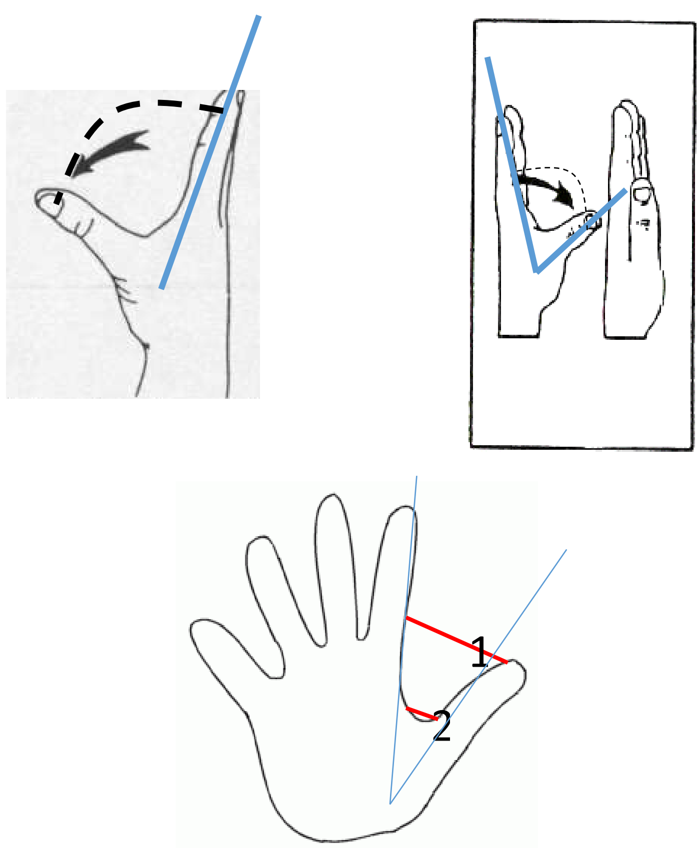


Figure 5: Depiction of thumb joint angles

In order to validate the final finger length measurements, worker feedback was used with a current glove on the market which had the chosen finger lengths. Sixty-three glovebox workers tried on this glove (with similar index finger and thumb dimensions to our new design), with an inner Anti-C glove and with a cotton inner liner (if they utilize liners regularly with GB work). They were then asked to rate on a scale from -2 to +2 the following features:

- Index finger length
- Thumb Length

Results from the survey to validate the finger length are show in Figure 6.

2 – Too long
1 – Slightly long
0 – Fits just right
-1 – Slightly too short
-2 – Too short

Score	Index	Thumb
-2	1	0
-1	3	3
0	42	37
1	16	20
2	1	3
total	63	63

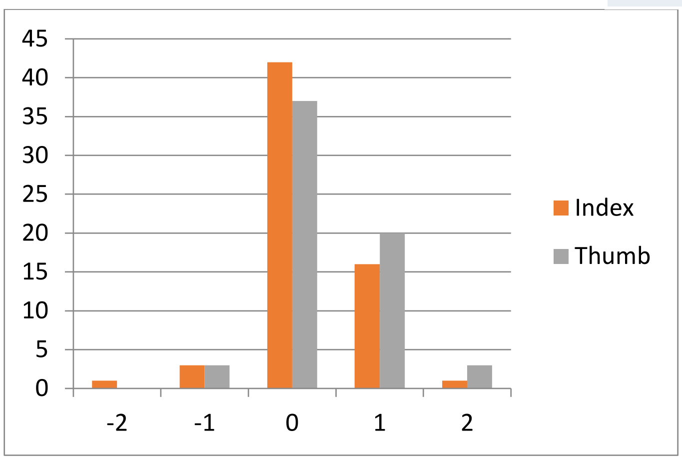


Figure 6: Results from survey to validate finger length

In summary, the final glove dimensions and glove design were calculated by comparison of literature review on hand anthropometrics, glovebox worker anthropometrics, understanding the present glovebox glove flaws, validation of finger lengths, and first prototype glove testing.

A CT scan of a hand was purchased and placed into a solid works model. An engineer, then adjusted the Solidworks model by first, implementing the new dimensions into the model and secondly, adjusting the model to incorporate the three angles for each of the finger joints (Figure 7,8). Orthopedic hand surgeons determined the finger joint angles (Table 5) to be used in the model which made a significant impact to the design. This research resulted in the final design resulting in the LANS Patent: <u>LANS 36USD1 "Protective Glove" (Figure 9).</u>

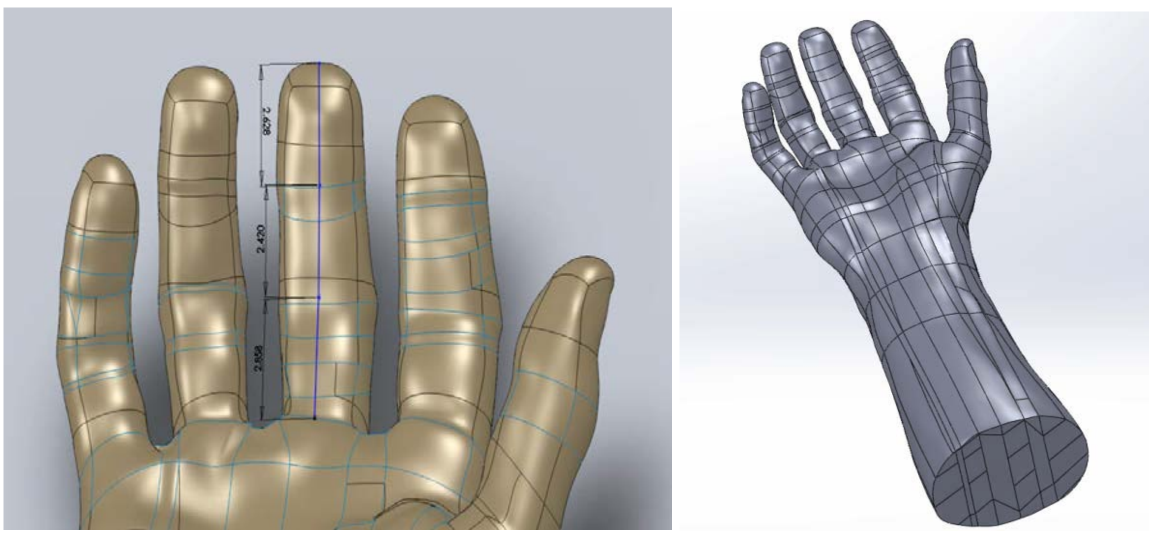


Figure 7: Solid works model with new glove dimensions and angles

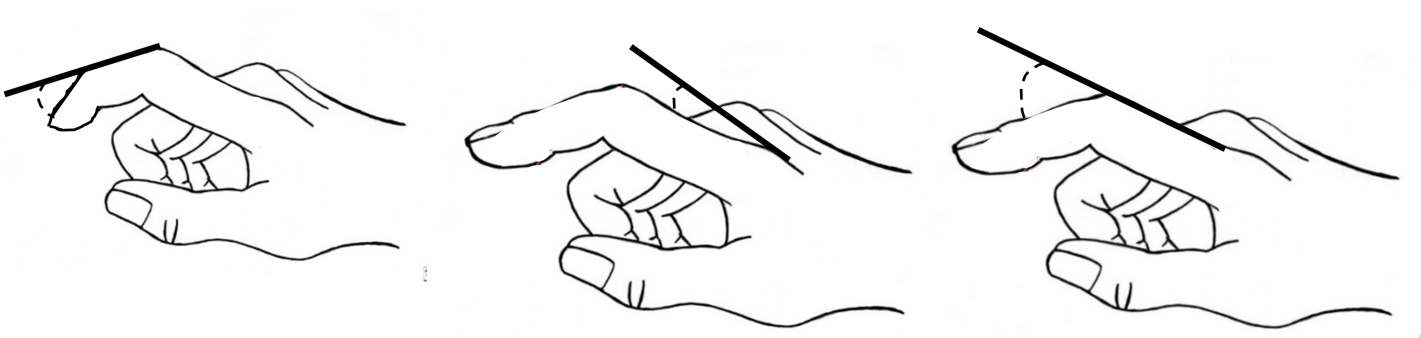


Figure 8: Depiction of the three finger angles

Finger Angles (degrees)	MP	PIP	DIP
Thumb	25		5
Index	22	30	5
Middle	14	32	5
Ring	10	36	5
Pinky	10	40	5

DIP: Distal Interphalangeal Joint
PIP: Proximal Interphalangeal Joint
MP: Metacarpophalangeal Joint

Table 5: Finger joint angles

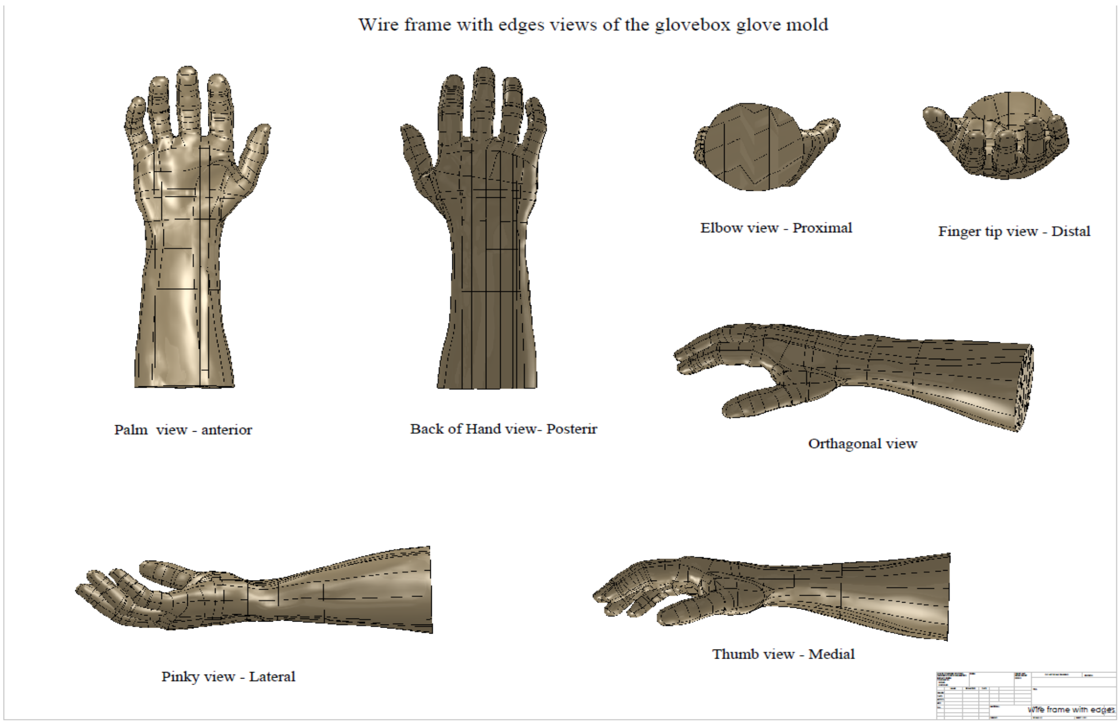


Figure 9: First design patent at LANL

3D models (Figure 10) were produced throughout the research course including the final model. The 3d models verified how accurately the solid works matched the desired design measurements.

Figure 10: Picture of 3 D models at various stages of development.

Once the final design was determined, a meeting with Honeywell (glovebox glove manufacturer) was conducted to see the possibility of producing the glove within the known LANL specifications. The manufacturer stated the fingers were too close together and thus would cause issues in production. The fingers spacing was changed in the 3D cad model to help with production. Once changed and initial approval was given by the manufacturer, a master mold (Figure 11) was produced by Shinko in Japan. The master mold was produced to fit the dipping requirements at Honeywell. All the desired dimensions were compared to the master mold and were within small fractional differences.

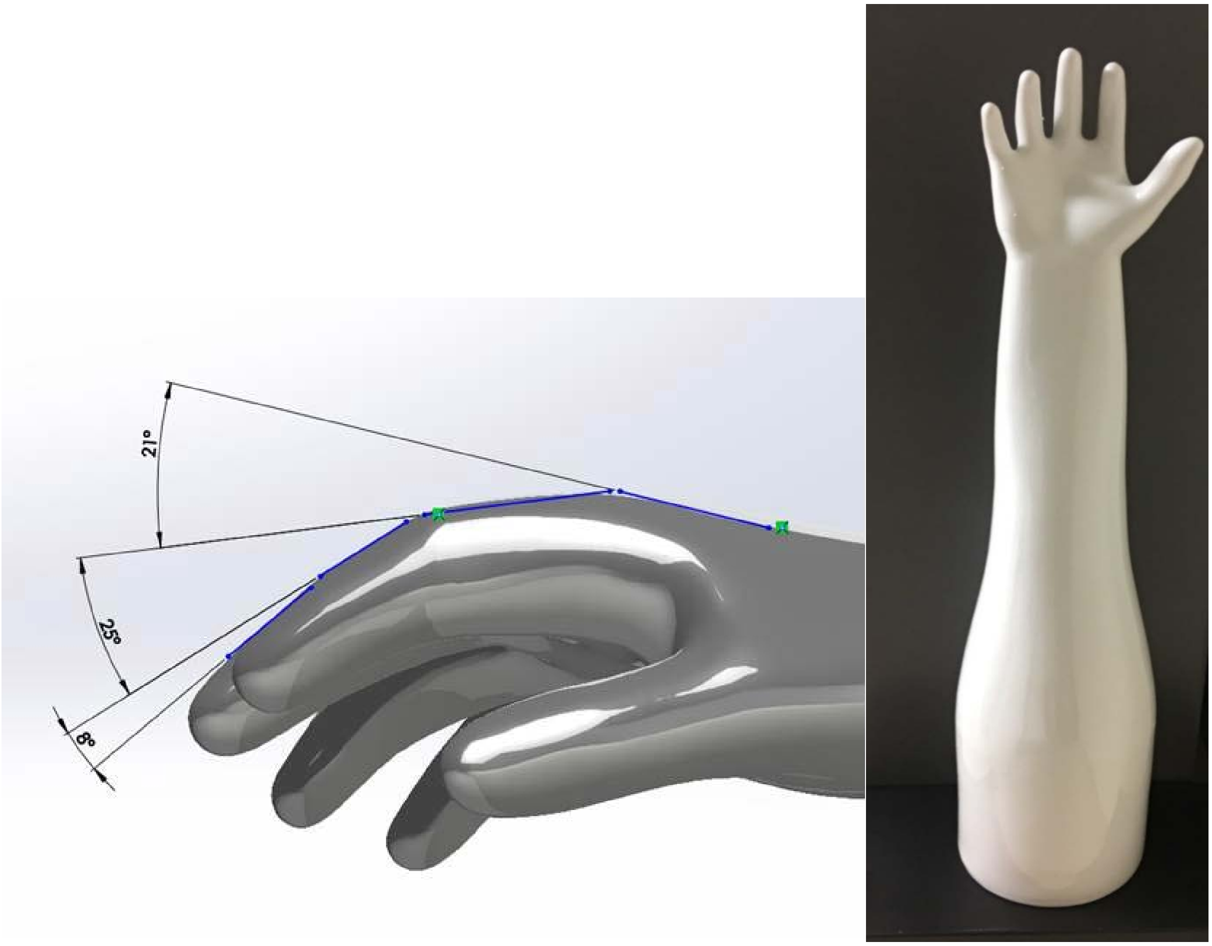


Figure 11: Master mold depiction

The first prototype glovebox glove was made as a 15 mil thickness CSM (hypalon) glove at the Honeywell facility. The project then conducted testing comparng this new ergonomically designed glovebox glove and the current glovebox glove used at LANL's Plutonium Facility (TA-55 glove). The study was approved by the Human Subject Review Boards of LANL and DOE. Seventy-two glovebox workers with varying years of experience from both LANL and Savannah River National Laboratory (SRNL) performed two trials of dexterity tests in both the new glovebox glove (prototype) and the present used glove (TA-55). The dexterity tests utilized were the Minnesota dexterity one-handed test, the Purdue one-handed test and two-handed assembly test, and the Bennett Hand-Tool dexterity test (Figure 12).

Figure 12: Bennett hand tool test board Minnesota dexterity test board

Purdue pegboard test board

For qualitiative data, each worker filled out a questionnaire and an opinion survey. The questionnaire included the number of years working in a glovebox, gender, the glove type used most often, cotton liner usage, size of Anti-C gloves, and dominant hand. The opinion survey asked a series of questions comparing the new prototype glove to the present glovebox glove. Their opinion was recorded regarding preferences of finger length, presence of tightness, thumb position, fit at web spaces, general comfort level, and ease of use with tweezers and grasping a can. Additionally, the workers tested the ease of getting in and out of both sets of glovebox gloves.
Statistical analysis was utilized to compare the new glovebox glove (prototype) to the present glovebox glove (TA-55). T – tests were utilized to determine if a significant difference existed in the performance of the dextertity tests. The prototype glove showed faster performance than the TA-55 glove in both the Bennett Hand-Tool dexerity test and Minnesota dexerity test ($p<0.02$, $p<0.0001$, respectively). There was no significant relationship between the gloves with the Purdue one handed test. The two handed Purdue test demonstrated a positive number. The more pegs the worker placed in a given time, the more successful the test, thus a positive value favors the prototype glove (Table 6)

	Minnesota	Bennet	Purdue One-Hand	Purdue Two hand
Sum	-39.2	-45.7	-.0128	4.340
Std Dev.	1.383	3.87	0.129	0.164
Mean	-.0853	-1.017	-.006	0.096
T-test P-value	0.000	0.025	0.558	0.000

Table 6: Statistical analysis results for the four dexterity tests

The prototype glove demonstrated less time to complete dexterity tests compared to the TA-55 glove. A distribution graph was plotted (Figure 13). This plot suggests the variability between the tests when using the prototype versus the standard TA-55 glove is larger with the Bennett test than with the Minnesota tests. The plot suggests that with the Minnesota and Bennett tests, there are more negative relative differences, meaning the workers performed the dexterity tests faster with the prototype glove. Regression analysis examined the relationship between survey demographics and dexterity test results; no statistically significant relationship was found.

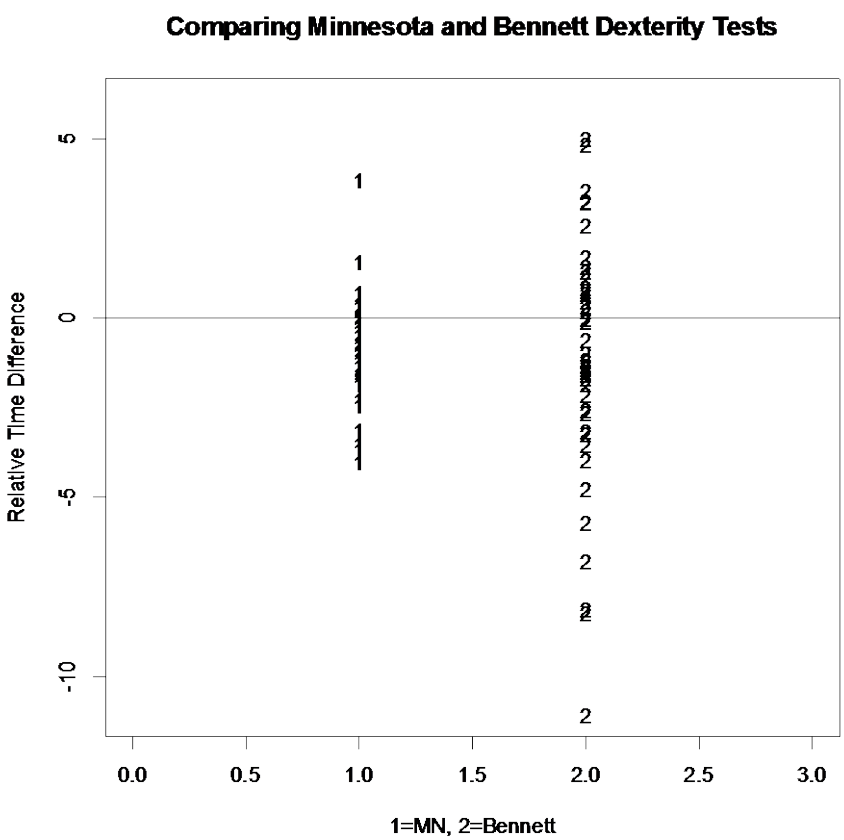
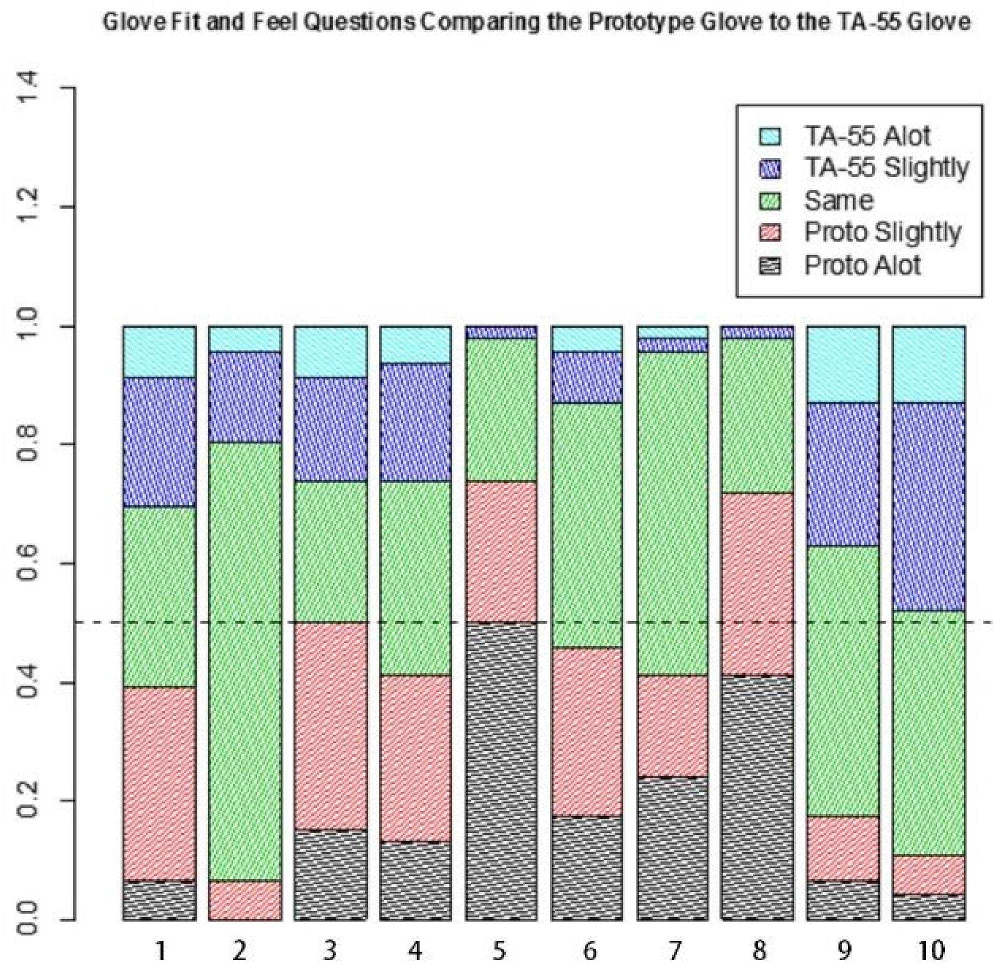


Figure 13. Distribution graph of the relative time differences between TA-55 glove and prototype glove for the Minnesota dexterity test (1) and Bennett Hand-Tool dexterity test (2).

Results from the questionnaire (Figure 14) demonstrated a strong worker preference for the prototype glove design. This preference was statistically significant in thumb positioning ($p<0.001$), finger web spacing ($p<0.002$), and finger length ($p<0.04$). The majority of workers found the prototype glove to be easier, also statistically significant, for tweezer use (p<0.001) and can grasping (p<0001). Approximately seventy percent of workers stated that the prototype glove is more comfortable at rest.



Column 1: Finger tightness
Column 2: Hand tightness
Column 3: Finger length
Column 4: Comfort
Column 5: Thumb position
Column 6: Web space
Column 7: Tweezer
Column 8: Grasping container
Column 9: Ease into gloves
Column 10: Ease out of gloves

Figure 14: Questionnaire results

In summary, three of the four dexterity tests demonstrated statistically significant results using the T-test analysis and a strong preference was noted by the employees during the questionnaire. Further demonstration of the results of the dexterity tests and questionnaire results are shown below in Figures 15-17. The prototype glove performed better during dexterity testing demonstrating preference for use as well as having potential to reduce ALARA.

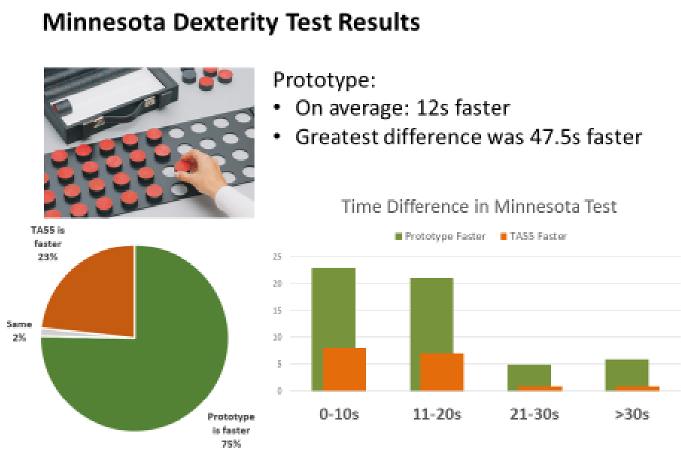


Figure 15: Minnesota dexterity test results

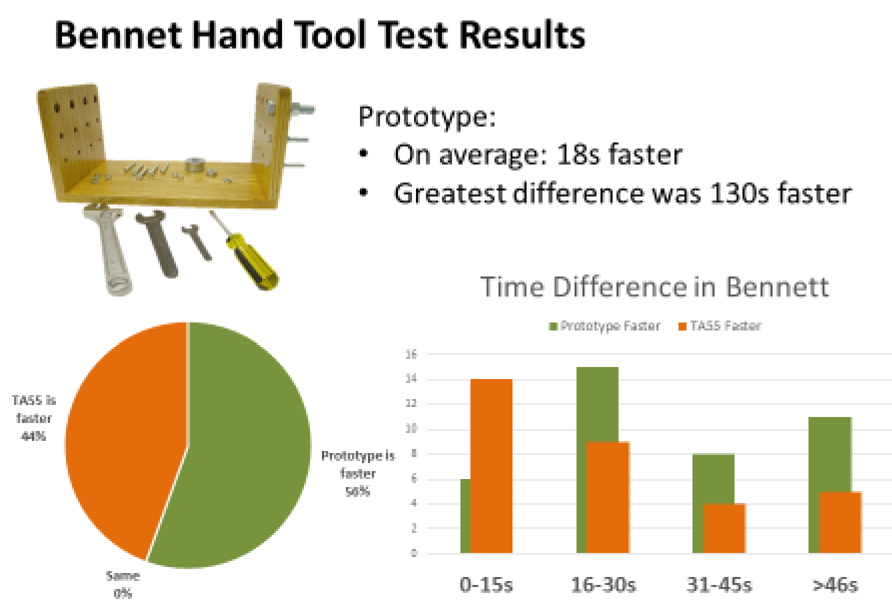
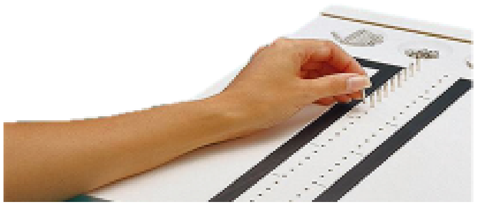
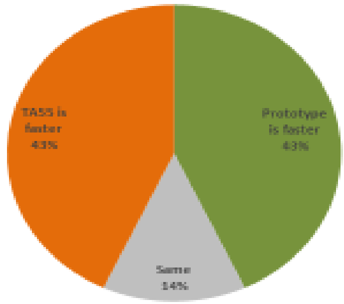


Figure 16: Bennet hand tool test results

Purdue One-Handed Dexterity Test Results

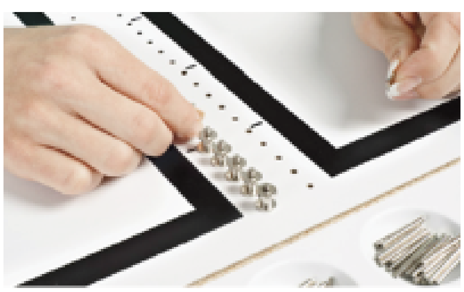
- No statistically significant difference in performance





Purdue Two-Handed Dexterity Test Results

- Prototype:
  - On average, scored 2.1 more pieces (18%)
  - Greatest difference was 6 more pieces



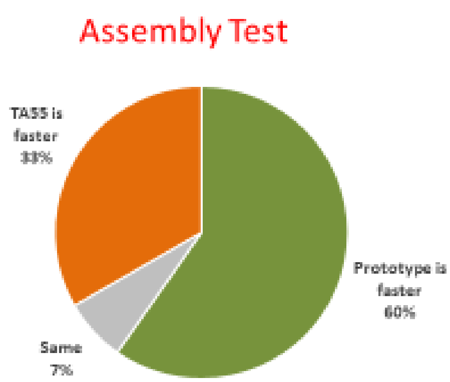


Figure 17: Purdue one and two handed dexterity test results.

Questionnaire results are shown below in Figures 18-20.

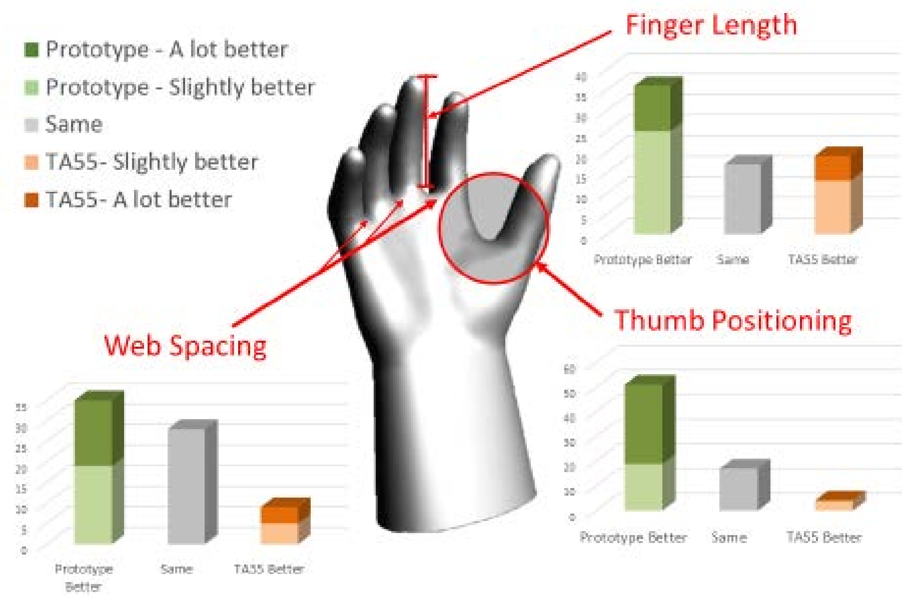


Figure 18: Finger length, web spacing, and thumb position results

Figure 19: Use of tweezers and container grasping results

The LANL glove (TA-55) was preferred for getting in and out of with approximately one-third of the employees feeling there was no difference. The results are included below in Figure 20.

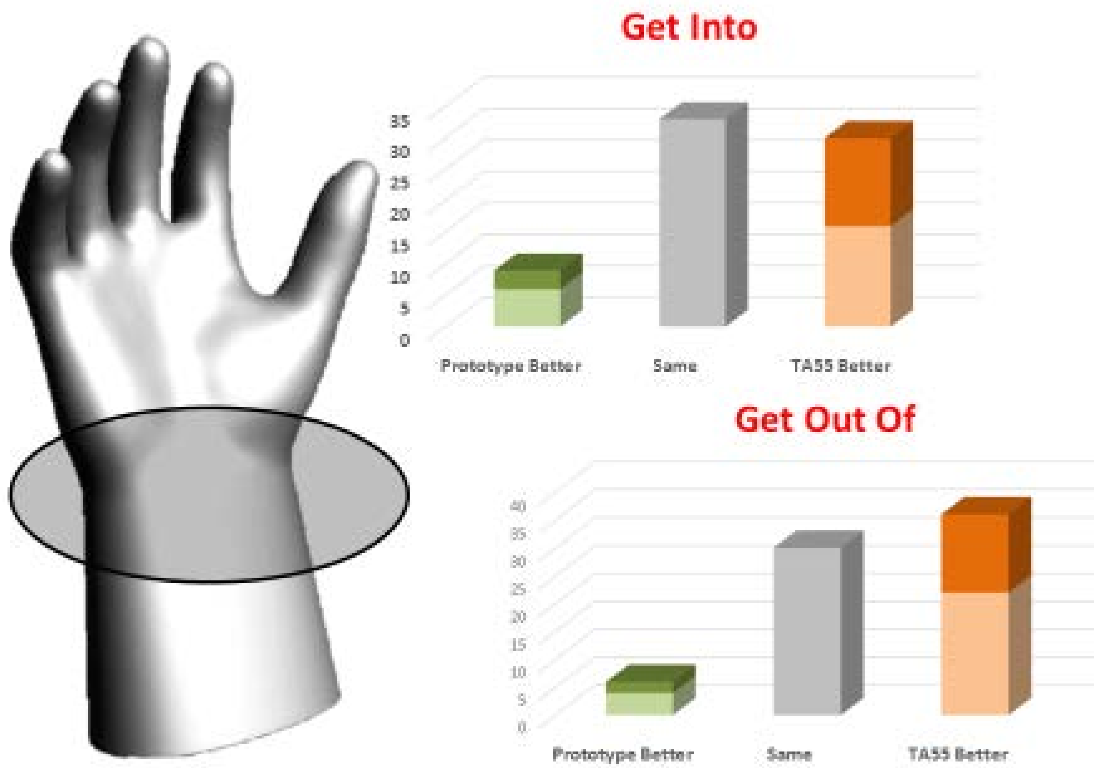


Figure 20: Results of getting in and out of the glovebox gloves

The design of the new glove has a significant angle change at the wrist. This was intentionally built into the design to help reduce the glovebox glove from slipping back as the worker performed tasks. The prototype glove being more difficult to get in-out of was expected due to this design feature. The questionnaire and dexterity tests showed definite promise for the new glovebox glove.

The last phase of this study was to work with the manufacturers for production. Unfortunately, after approximately 50 test production trials, Honeywell ended the project. The production/failure rate was too great for them to continue. The difficulty was determined to be at the thumb position. This area was creating bubbles during production. Piercan, USA is a second USA manufacturing company. The 3D model along with the prototype was brought to Piercan to see if they had the capability of production without bubbling. The company felt there was an 80% chance of success in production. New molds to fit Piercan's manufacturing process were made by Shinko. The glove was made at Piercan on trial number 2 with small flaws. The glove inspection report is attached as Appendix A. The glove was then given to LANL quality inspection team with the following being noted:

- Insufficient markings inside the glove
- Creases were found in the following locations:
  - Left Glove: 1 crease at thumb crotch and 2 creases at 12.5 inches from cuff
  - Right Glove: 3 creases along fold and one small crease in thumb crotch

Due to the inspection team finding some quality issues, the glove then went to the glovebox glove subject matter expert (SME). The left glove would have been deemed as a rejection and the right glove would have passed the inspection process. The insufficient markings were not of concern; as it can be easily mitigated by the manufacturer. The ability for Piercan to produce a glove that passed both LANL standards at the manufacturer and the SME inspector leads to the ability for the company to produce the glovebox glove with this design criterion.

FIGURES

TABLES

1 INTRODUCTION

Many industrial applications require the use of a glovebox (GB) in order to manipulate objects within a contained environment. Gloveboxes are essential to the pharmaceutical, semi-conductor, nuclear and other biochemical industries, as the target materials may include alpha-emitting particles that can cause harm to the worker and environment [1], or the environment contains particulates than could harm the product. While gloveboxes serve as effective containment systems, they are often extremely difficult to work within and their operation typically presents a number of ergonomic hazards.

For the past eight years, scientists, ergonomists and physical therapists have monitored the effects of the high workload associated with GB work in over 400 GB workers at Los Alamos National Laboratory (LANL). The ergonomics team at LANL has tracked injury and symptom incidence in this population via medical screens, worker-completed surveys, and independent report. This data collection has led to the discovery that injuries to both the elbow (lateral epicondylitis) and thumb (De Quervain's disease) are common. The scientists have tracked both glove breaches and failures. A glove breach is defined as "an unplanned opening in a glove caused by mechanical damage during operations" such as a puncture or a pinch causing a tear through the glove. A glove failure is due to wear on the glove, which leads to material degradation over time [1]. The present glovebox glove design has been directly related as a causal effect in worker injuries, glove breaches and glove failures. Despite the mechanical shortcomings and ergonomic injuries, the LANL glovebox glove design has not been changed in 60 years. The need for a new design is crucial to resolve the above mentioned issues.

Lateral epicondylitis, also referred to as "Tennis Elbow", is an overuse injury. It is characterized by pain in the lateral elbow, with increased irritation when the wrist is in extension. Medical screening for lateral epicondylitis includes pain during elbow palpation, resisted extension of wrist and reduced strength with resisted grip [2,3]. De Quervain's disease affects the thumb and is considered a tendon related disorder [4]. A systematic literature review demonstrated ergonomically stressful manual work, repetition, and force was associated with De Quervain's disease [5]. The number of glovebox workers experiencing symptoms related to ergonomics increases as the number of years performing glovebox work increases. A recent survey performed at LANL revealed 50% of glovebox workers report having symptoms after working 25 years in a glovebox [6]. Improving the design of the glove could reduce the forceful grip and stress on the tendons that causes the above conditions. Glove fit and glove thickness are the two major contributory factors that influence dexterity [7]. The most common glovebox gloves used at LANL are 30 mils in thickness, with leaded and unleaded versions. This makes dexterity especially difficult with the added glove weight. A study in 2004 determined that glove thickness has the greatest negative effect on dexterity test rates [8]. However, the material thickness cannot currently be addressed due to exposure safety, but improving dexterity through design fit changes is a possible accomplishment. Improved dexterity will also allow workers to complete their tasks at a faster rate - (hence decreased exposure time) helping to keep within ALARA (As Low As Reasonable Achievable) government standards. Improving dexterity allows work tasks to be performed more comfortably, easier with less fatigue, and quicker, thereby reducing exposure time.

Glove breaches and failures are also a direct result of this flawed design. According to LANL data on glove failure occurrence, more than a third of failures occur at the index finger and thumb due to pulling/stretching of the webspace while opening the hand. The present design has a V-shape at the thumb webbing, yet the hand anatomy is a C-shape. By reconfiguring the placement of the thumb, the physical stress on the glove would be reduced. This would lead to a reduction in failure rate. Glove breach reduction would be a direct result of improving dexterity allowing workers to perform tasks easier and with less risk of puncturing and tearing.

Designing a new glove which will reduce injuries, glove breaches and glove failures is a complicated project. In 2009, NASA hosted a contest for a redesign of the astronauts' space glove to provide better dexterity, while maintaining protection [9]. The top prizes were awarded to an artist and an engineer for independent designs which improved flexibility and reduced fatigue that was normally felt by astronauts in their current gloves [10]. The success of the NASA challenge involved designing for a select group of individuals, where hand measurements could easily be taken and used in the specific glove design. This glovebox glove design project must consider all glovebox workers and thus brings on a higher level of difficulty. The new design must incorporate the varied physical attributes of thousands of glovebox workers in a vast array of industries, with anthropometrics dimensions from the 5th percentile female to the 95th percentile male, all using the same size glove to perform the necessary work tasks.

In order to address the principal design components, it was necessary to call upon three different disciplines for unique contributions to the project; ergonomics, hand orthopedics, and engineering. The ergonomics constituent was instrumental in conducting an extensive review of the anthropometric data available for hand measurements. They were also most familiar with the ergonomic injury and breach/failure rates at LANL. A hand surgeon from the University of New Mexico was responsible for relating knowledge of the functional hand to the project and determining glove design characteristics that were critical to reduce injuries. Finally, the engineering partner was essential for design implementation. The team was able to identify the shortcomings of the present glove and determine which changes would bring the most improvements to reduce injuries and failures.

The main concerns with the current design are: short fingers, inappropriate length from the wrist to finger webbing, nonexistent joint angles and incorrect thumb placement [11]. The length of the fingers on the glove is a serious consideration, due to the incorrect application of force that results from this design flaw. While it is important to reach the end of the fingertip during pinching movements, too short of fingers moves the glove webspace distally. This design causes the torque used in a grasping motion to be transferred from the metacarpophalangeal (MP) joints of each finger, to the DIP and PIP joints, which cannot handle the same load. This results in excessive force to hold objects causing increase fatigue and risk of injury. The present anatomical placement of the glove's thumb is a V-shape at the webbing between the thumb and index finger. Grasping around an object pulls on the V causing excessive stress to the glove material adding to wear issues. The V also adds excessive stress to the thumb by constantly extending the thumb against resistance of the glove material leading to the forementioned thumb injury. A C-shape is more natural for cylindrical grasping [12], a basic type of prehension, as defined by Schlesinger [13].

3D modeling is a common-place tool for aiding in design. This engineering program would incorporate the anthropometric data from the ergonomics team and the functional hand anatomy from the medical team to form a manufacturable model. The model could then be made into an anatomically correct glove which could be tested against the presently used glovebox glove. The Minnesota Dexterity test has proven effective as a reliable measuring tool for dexterity with glovebox operaters [8]. Two different tests associated with the Minnesota Dexterity kit: The One-Handed Test, and the Two-Handed Test have been used extensively for industry screening for procedure or equipment impact on task times and there is normative data associated with them. There are other dexterity tests as well to determine the ability of workers to perform tasks such as the Purdue Pegboard Test and the Bennet Hand tool tests [14, 15] Questionnaires are commonly used to ascertain worker comfort and opinion towards new products. This proven methodology was chosen to test the hypothesis of this study which is an improved glove design, that is anatomically correct, will result in worker preference and improved dexterity.

2. Summary, Conclusion and Recommendation

A new design for a glovebox glove was developed by a team, including ergonomists, orthopedic hand surgeons, and engineers. The new designed glovebox glove has over 40 dimensions to correlate closer with the anatomy and biomechanics of the human hand. Glovebox workers at two different DOE facilities tested the new glove resulting in statistically significant improvements for both the questionnaire and dexterity tests. Although one glovebox glove manufacturer was unable to make a quality glove product, a second manufacturer was able to produce the new designed glove. The company was able to manufacture it; holding up to the stringent inspection criteria for a plutonium facility. The new glove has great promise to improve worker comfort, reduce risk of injury, and mitigate glove failures and breaches. In conclusion, the new glove will improve safety of the workforce.

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APPENDIX A

PIERCAN USA, Inc.

Ergonomic Glove Production Trial

Los Alamos National Laboratory

Mario Figueroa
8/30/2017
Quality Report # 083017-1

SUMMARY

A production trial run was conducted using 4 special molds supplied by LANL to determine the producibility of the ergonomic glove design. The molds were on 2 separate runs, resulting in 4 pairs / 8 gloves total. The gloves were subjected to standard inspection, air leak and mechanical testing to determine the quality and performance of the finished gloves.

The results indicate Piercan USA has the capability to produce quality gloves using the ergonomic glove design with minor adjustments to its standard production process. The results from the measurements and tests conducted on the gloves produced are outlined below.

GLOVE DIMENSIONAL MEASUREMENTS:

Dimensional measurements were conducted on 6 gloves. Glove thickness is a critical indicator for production capability and glove performance. To characterize glove thickness consistency and variability, test locations were added over the length of the sleeve including the center of the wrist, which is not normally measured. In addition, both single layer and double finger thickness measurements were conducted again to ensure material consistency which is most geometrically challenging. Port size and hand size were verified to match the mold. A total of 28 thickness measurements were taken on each glove with the location of these shown on figure 1 below.

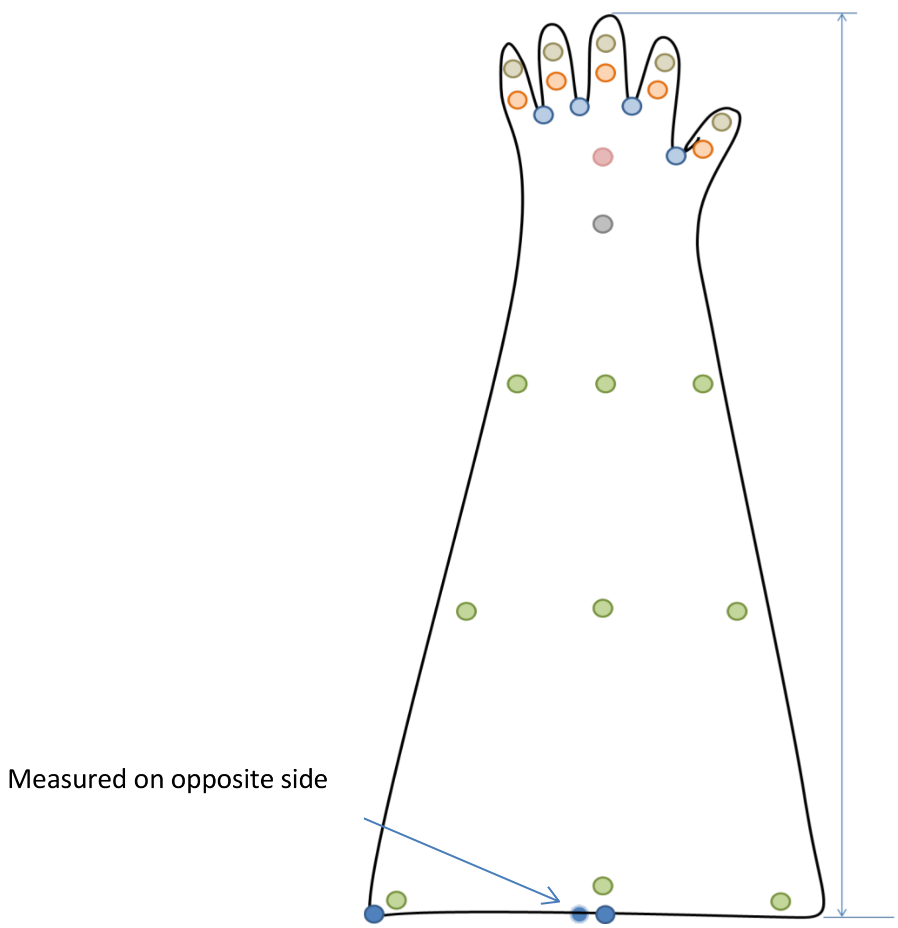

Figure 1. Location of Measurements

The results for each measurement on each of 6 gloves are recorded in the following tables. As mentioned, the gloves were produced under 2 separate job orders (#7278 and #7298) conducted 3 days apart, to ensure all possible natural variability was represented. Each job order run was for 4 gloves, for a total of 8 produced but 2 were rejected during production for material inclusions and inconsistencies. These were used for destructive mechanical testing including tensile force, % elongation and puncture resistance. The results for each point measured on each of the remaining 6 gloves are shown in the 3 tables that follow.

DATE	*Glove*	*BEAD 1*	*BEAD 2*	*BEAD 3*	*SLEEVE 1*	*SLEEVE 2*	*SLEEVE 3*	*SLEEVE 4*	*SLEEVE 5*	*SLEEVE 6*	*SLEEVE 7*	*SLEEVE 8*	*SLEEVE 9*
7/5/2017	1	0.1885	0.1675	0.182	0.021	0.0205	0.02	0.0265	0.026	0.025	0.0305	0.0285	0.0275
7/5/2017	2	0.159	0.1655	0.185	0.0195	0.0185	0.0185	0.026	0.026	0.025	0.0295	0.0285	0.0285
7/12/2017	3	0.165	0.1665	0.1635	0.0265	0.0255	0.025	0.028	0.028	0.0285	0.0285	0.029	0.026
7/12/2017	4	0.178	0.183	0.1805	0.023	0.0255	0.025	0.03	0.029	0.0255	0.0315	0.0315	0.0315
7/12/2017	5	0.178	0.1815	0.179	0.0255	0.0255	0.024	0.0295	0.028	0.03	0.0315	0.031	0.0305
7/12/2017	6	0.1575	0.172	0.1845	0.025	0.026	0.025	0.0285	0.029	0.0285	0.0305	0.0295	0.0295
		0.171	0.173	0.179	0.023	0.024	0.023	0.028	0.028	0.027	0.030	0.030	0.029

Glove	PALM	CROTCH 1	CROTCH 2	CROTCH 3	CROTCH 4	FINGER 1	FINGER 2	FINGER 3	FINGER 4	FINGER 5
1	0.025	0.028	0.033	0.026	0.035	0.031	0.038	0.038	0.042	0.034
2	0.025	0.030	0.026	0.028	0.030	0.032	0.037	0.038	0.036	0.036
3	0.025	0.036	0.023	0.025	0.030	0.030	0.031	0.035	0.035	0.034
4	0.025	0.033	0.025	0.034	0.031	0.029	0.032	0.032	0.037	0.035
5	0.025	0.030	0.029	0.023	0.029	0.038	0.037	0.040	0.038	0.031
6	0.024	0.030	0.024	0.026	0.025	0.028	0.035	0.033	0.038	0.033
AVG	0.025	0.031	0.027	0.027	0.030	0.031	0.035	0.036	0.038	0.034

Glove	DOUBLE FINGER 1	DOUBLE FINGER 2	DOUBLE FINGER 3	DOUBLE FINGER 4	DOUBLE FINGER 5	LENGTH	WRIST
1	0.056	0.053	0.044	0.052	0.056	33.500	n/a
2	0.056	0.055	0.049	0.060	0.057	33.000	n/a
3	0.055	0.055	0.057	0.052	0.057	33.250	0.028
4	0.059	0.052	0.051	0.052	0.057	33.000	0.027
5	0.063	0.050	0.054	0.058	0.054	33.000	0.028
6	0.057	0.063	0.058	0.055	0.054	33.000	0.027
AVG	0.057	0.055	0.052	0.055	0.056	33.125	0.027

Tables 1 - 3. Thickness in Inches for each point measured

The standard specified single layer wall thickness for a 15 mil glove is 0.0120” minimum and .030” maximum. Double layer thickness is 0.024” to 0.070” . Bead thickness diameter is 0.125” to 0.250” .

The data shows the process ran at the high end of the thickness tolerance and slightly above. This can be adjusted if required during operation on normal production runs.

MECHANICAL PROPERTIES

The 2 gloves rejected during production were used to conduct mechanical tests including Tensile Yield Force and % Elongation. Another 2 gloves, one from each job order, were used to test puncture resistance. The results are in table 4 below.

Glove	***Tensile Strength - psi***	***% Elongation***	***Puncture Resistance (n)***
7	3852	678%	Not Measured
8	4327	669%	Not Measured
3	Not Measured	Not Measured	73.5
5	Not Measured	Not Measured	68.7

Table 4. Mechanical Properties Test Results

The specifications for Polyurethane gloves are; Tensile Strength >3500psi; Elongation > 500%; Puncture Resistance > 50n.

AIR LEAK TESTING:

The 6 gloves used for thickness measurement were also tested for Air Leak per AGS-005-2014 which calls for gloves to be filled with enough air to hold a horizontal position. After 1 hour, no drop in horizontal position should be detected. All 6 gloves passed this test.

CONCLUSION:

The 2 pairs of gloves remaining after testing along with corresponding test data were delivered to Cindy Lawton during her visit to Piercan USA on 7/24/17 to evaluate at LANL. No feedback has been received as of the date of this report.

Based on the results of inspection and tests conducted from this trial production run, Piercan USA is capable of producing the LANL ergonomic glove design.

Mario Figueroa: Date: 8/30/17

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