U.S. Army
Chemical Materials Agency

Project Manager for
Non-Stockpile Chemical Materiel

X-Ray Assessment of 155mm Mustard Projectiles Stored at Blue Grass Army Chemical Activity, Richmond, Kentucky

Final
Revision 1

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EXECUTIVE SUMMARY

This report, *X-Ray Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity, Richmond, Kentucky*, summarizes a mutual effort by the U.S. Army Element, Assembled Chemical Weapons Alternatives (USAE ACWA) and the U.S. Army Chemical Materials Agency (CMA) to collect data concerning heels or hardened mustard agent, which have formed on the interior of M110 mustard (H)-filled 155 millimeter (mm) projectiles stockpiled in igloos managed by the Blue Grass Chemical Activity (BGCA).

A work plan titled *Blue Grass Army Depot and Blue Grass Chemical Activity Work Plan for Chemical Projectiles External Movement and X-Ray Assessment of Mustard Projectiles* was developed in October 2010 to assess H-filled 155mm projectiles at BGCA. The work plan was approved by the Kentucky Department of Energy and Environment Cabinet, Division of Waste Management, on 14 January 2011.

The sampling effort was carried out by BGCA, the U.S. Army 20th Support Command Chemical, Biological, Radiological, Nuclear, and High Yield Explosive (CBRNE), Chemical Analytical and Remediation Activity (CARA), CMA Stockpile Management Office (SMO), and the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM).

The assessment study had the following objectives:

1. Determine the amount of heel in a representative sample of H-filled 155mm projectiles at BGCA. The assessment results will provide insight as to the quantity of heel that can be expected in the rest of the BGCA H-filled 155mm stockpile.

2. Collect observations regarding the condition of the sampled munitions that may contribute to an understanding of what can be expected in the remainder of the stockpile.

3. Determine the heel and liquid fill levels in previously overpacked munitions.

The presence of heel in H-filled munitions has caused processing challenges in operations at other sites. This experience has generated concern that similar processing challenges may occur when the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) begins processing the mustard munitions at BGCA. Analysis of the results obtained during assessments detailed in this report will be used to predict what portion of the stockpile contains heel and how much heel can be expected.

The project consisted of two phases. Phase I extended from approximately June 2010 to April 2011 and consisted of project planning and preparation. Planning included determination of the sample size, setting the sample selection criteria, and defining assessment procedures. Preparation included selection of the 96 munitions to be examined, visual inspection of the munitions, overpacking of the munitions, and movement of the munitions from their storage igloos to the assessment igloo. Phase II was performed from 9 May to 14 June 2011 and consisted of an X-ray examination of the 96 sample munitions as well as X-ray examination of 80 previously overpacked munitions.

All of the 96 stockpiled munitions assessed contained heel. The smallest amount of heel observed was approximately 15 percent while the average percent heel was determined to be 54.8 percent, thus revealing that on average, more than half of the fill material in the X-rayed munitions has been converted to or is trapped within a heel. Evaluation of the heel data from igloo to igloo, from location to location within an igloo, and by lot number did not reveal any statistically significant patterns.

Based on evaluation of heel amounts found in the 96 sample munitions, an estimate was made regarding average heel that might be found in the remainder of the H-filled 155mm shells at BGCA. The average amount of heel expected is between 50.6 percent and 59 percent with a standard deviation of 20.5 percent. Based on these values and assuming a normal distribution, it is estimated that approximately 3,000 munitions will have between 50 percent and 59 percent heel and approximately 6,100 will have greater than 59 percent heel.

Regarding the 80 previously overpacked munitions (known leakers) that were X-rayed, liquid was seen inside the fuze well of 36 munitions. Two of these 36 munitions also showed a small amount of liquid inside the overpack (outside of the munition). These observations are directly related to the reason these munitions had previously been overpacked and are not a reflection of what to expect in the stockpile as a whole.

Temperature data was collected during the X-ray examination process to verify that the temperature in the assessment igloo was above 58°F, the freezing point of mustard agent. Four sets of temperature data were recorded: air temperature inside the igloo and temperatures of three Simulation Equipment Test Hardware (SETH) munitions (one located in the front of the igloo, one in the middle, and one in the rear). Temperature measurements indicated that the munitions were above 66°F leading to the conclusion that any solid material seen inside the agent cavity was heel and not frozen liquid. A statistical analysis was performed on the temperature data collected. Results concluded that the assumption regarding temperature fluctuations in the front of the igloo were not supported as the greatest temperature fluctuations were in the rear of the igloo. Furthermore, the highest average munition temperature was found furthest from the door and the coolest at the front location. Temperature comparisons of the front, middle, and rear locations within the igloos were also performed; the differences in temperatures between the three locations were statistically significant.

This assessment report provides documentation that supports the statistical analysis of the assessment operations performed in accordance with the *Blue Grass Army Depot and Blue Grass Chemical Activity Work Plan for Chemical Projectiles External*

Movement and X-Ray Assessment of Mustard Projectiles, October 2010. The principal investigator of the assessment operation was Mr. Russell Fendick, CMA.

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SECTION 1
INTRODUCTION

This report, *X-Ray Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity, Richmond, Kentucky*, summarizes a cooperative effort between the U.S. Army Element, Assembled Chemical Weapons Alternatives (USAE ACWA) and the U.S. Army Chemical Materials Agency (CMA) to collect data concerning congealed or solidified heels that have formed on the interior of mustard (H)-filled 155 millimeter (mm) projectiles stockpiled in igloos managed by the Blue Grass Chemical Activity (BGCA).

The presence of solid residue in significant amounts could present a problem for removal of energetic components and mustard agent from the projectiles during weapons destruction efforts at the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP).

In October 2009, a scope of work was developed for assessing H-filled 155mm projectiles at the BGCA. A statistically based sampling plan was then developed by Noblis of Falls Church, Virginia, from April through June 2010, *Statistical Sampling Plan for Non-Intrusive Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity*, June 2010. During that same time frame, the BGCAPP Field Office (FO) developed an igloo-directed sampling approach where the individual munitions would be chosen based on the sample size from the Noblis statistical sampling plan. A work plan was subsequently written by the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM) and BGCA and was approved by the Kentucky Department of Energy and Environment Cabinet, Division of Waste Management, on 14 January 2011. The work plan, titled *Blue Grass Army Depot and Blue Grass Chemical Activity Work Plan for Chemical Projectiles External Movement and X-Ray Assessment of Mustard Projectiles*, addressed the non-emergency handling, movement, overpacking, and non-intrusive assessment of H-filled projectiles.

The sampling effort was implemented by BGCA, the U.S. Army 20th Support Command Chemical, Biological, Radiological, Nuclear, and High Yield Explosive (CBRNE), Chemical Analytical and Remediation Activity (CARA), the CMA Stockpile Management Office (SMO), and PMNSCM.

Non-intrusive analysis of all items stored at the Blue Grass Army Depot (BGAD) was determined to be impractical due to the expense, time, and logistics required as well as potential safety and/or environmental risks. Therefore, the chosen and customary approach was to select a representative sample of items, assess the items, and apply statistical methods to the results to develop a probability distribution of the number of munitions with heel in the BGCA stockpile and the amount of heel present in a munition.

This assessment report provides documentation on the assessment activities performed in accordance with the *Statistical Sampling Plan for Non-Intrusive Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity*, October 2010, and provides a statistical analysis of the sampling data.

1.1 Background/History

As part of the Army's Chemical Stockpile Disposal Project, BGCA stores chemical weapons until they can be safely disposed. BGCA stores 523 tons, approximately 1.7 percent, of the original U.S. stockpile of chemical weapons. Among the items stored at BGCA are approximately 15,000 M110 H-filled 155mm projectiles. The H-filled 155mm munitions are stored in igloos and are distributed among three lot numbers.

According to the Noblis sampling plan, the munitions were assigned to BGCA lot numbers in 1954 and 1955. Each lot was made up of munitions from a collection of manufacturing lots. Table 1-1 lists the BGCA lot numbers, the percentage of 155mm munitions in each lot, and the original manufacturing lot numbers.

The Noblis sampling plan examined the commonality between the three BGCA lots and determined sharing scores of 79 percent for lot BGD-655-5, 55 percent for lot BGD-655-7, and 58 percent for lot BGD-655-9. These scores indicate a high degree

Table 1-1. BGCA H-filled 155mm Munitions by Lot Number

BGCA Lot Number	Percent of All 155mm Munitions	Original Manufacturing Lot Numbers Included in BGCA Lot Number
BGD-655-5	12 percent	EA-4-10, 13, 15, 20, 21, 24, 25, 27, 29, 31, 39, 41
BGD-655-7	58 percent	EA-4-3, 6, 7, 9, 10, 12, 13, 19, 20, 21, 22, 24, 25, 26, 27, 29, 30, 31, 32, 33, 34, 35, 37, 38, 39, 40, 41, 46
BGD-655-9	30 percent	EA-4-1, 3, 7, 8, 9, 10, 13, 19, 21, 23, 25, 26, 29, 30, 31, 32, 33, 34, 35, 38, 39, 40, 41, 44

Source: Noblis. *Statistical Sampling Plan for Non-Intrusive Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity*. June 2010.

Note:

BGCA = Blue Grass Chemical Activity

of commonality between the three BGCA lots. Therefore, the three BGCA lots should have relatively consistent properties.

The mustard agent was manufactured between 1941 and 1943 at the Edgewood Area (EA) of Aberdeen Proving Ground, Maryland. Currently, the manufacture date of mustard agent is the only historical information available for these munitions; projectile parts, including bursters and projectile shells, have manufacture dates ranging from 1941 to 1943. According to the Noblis sampling plan, it was assumed that the manufacturing facilities, equipment, methods, and procedures used to manufacture the agent in each munition were equivalent. The munitions have been in storage at BGCA since the 1940s. A schematic diagram of an M110 155mm projectile is presented in figure 1-1.

BGCAPP is being built to safely and efficiently destroy the stockpile of chemical weapons by utilizing an agent neutralization process followed by a supercritical water oxidation (SCWO) method to treat the caustic hydrolysate, which is created during destruction of agent.

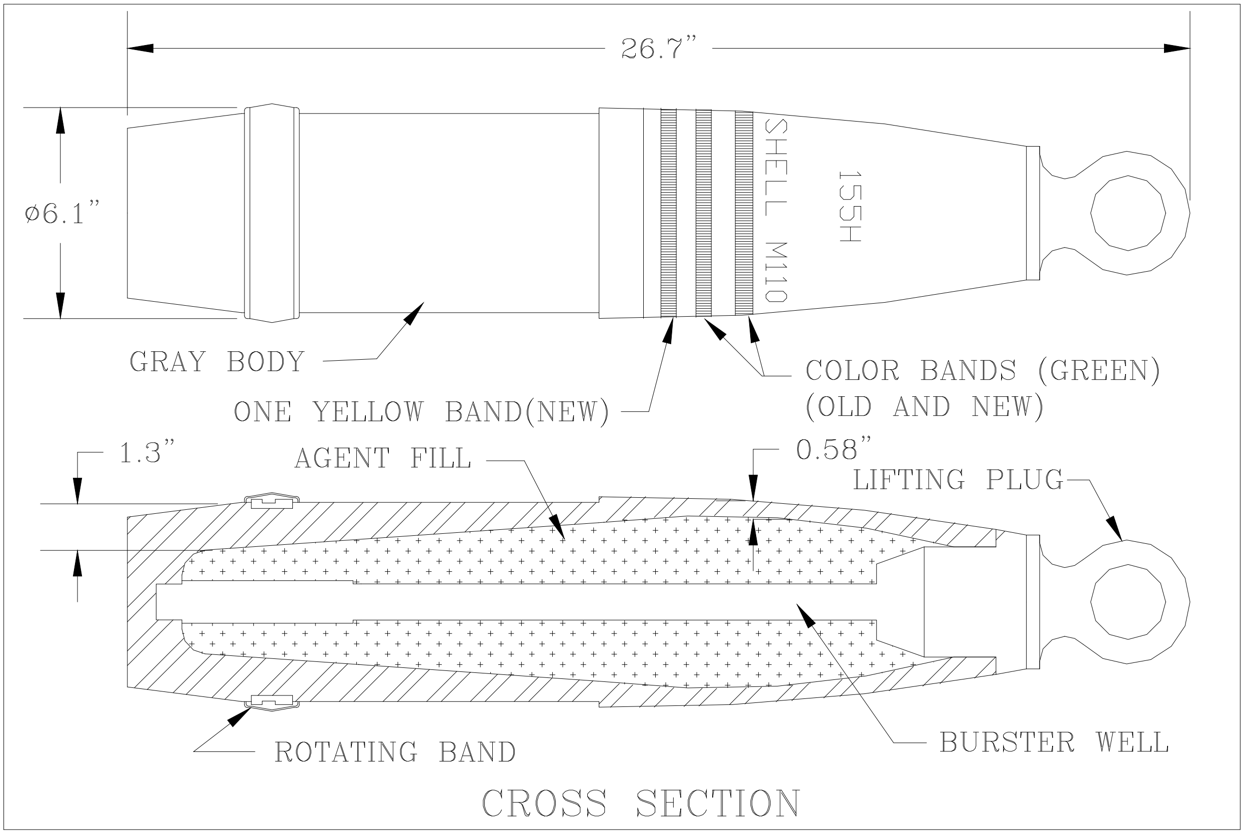


Figure 1-1. M110 155mm Projectile Configuration

The presence of heels, the tendency of mustard to become congealed or hardened, in the H-filled munitions has caused processing challenges at other demilitarization sites, which has generated concern for future operations at BGCAPP. Past operations at the Johnston Atoll Chemical Agent Disposal System (JACADS) found that 155mm distilled mustard (HD)-filled munitions contained between 22 percent and 66 percent heel. Drain tubes used at JACADS often became clogged, requiring unplanned maintenance. Experience at Tooele Chemical Disposal Facility (TOCDF) revealed difficulties pulling the bursters from munitions due to solidified mustard heel; the draining process was also hindered by the presence of heel.

While design for BGCAPP systems such as the Munitions Washout System (MWS) have taken past experience into account, it is still of interest to know as much as possible about the munitions stored at BGCA to ensure that as many unplanned events are avoided as possible.

In addition to the potential problems posed by heel, demilitarization efforts at TOCDF revealed that a number of leaking and rejected munitions presented added challenges as these munitions could not be processed. Therefore, in addition to obtaining information about heel in the BGCA stockpile, ACWA and BGCAPP are interested in characterizing previously overpacked munitions (known leakers) to better understand the potential problems they may present during processing at BGCAPP.

As a result of past baseline site experiences, the focus has been on the ability of BGCAPP to effectively access and remove the energetics, drain liquid agent, and wash out mustard heel from the 155mm munitions. The Program Manager ACWA (PM ACWA), BGCAPP FO, and BGCA have worked with PMNSCM to assess the work plan and statistically based sampling plan in support of the non-intrusive analysis of the stockpiled and previously overpacked munitions at BGAD.

1.2 Purpose

From 9 May to 14 June 2011, an X-ray assessment was performed to assess 96 stockpile munitions and 80 previously overpacked munitions. The purpose of the assessment was to determine how much heel was present in H-filled 155mm projectiles awaiting destruction at Blue Grass and to assess previously overpacked munitions in order to better characterize their condition.

This assessment report analyzes the effectiveness of the sampling plan that was undertaken to assess the presence and probable distribution of heels in the H-filled 155mm projectiles stored at BGAD. The assumptions of heel predictability based on temperature levels and location or lot number are analyzed and information on previously overpacked munitions is presented.

1.3 Scope

The project scope required the selection of a sample of 96 projectiles from the stockpile along with 80 previously overpacked munitions staged in the leaker hazardous waste storage unit (HWSU). The selection of the 96 projectiles consisted of 32 items from each of three different 155mm storage igloos. Upon selection, the munitions were overpacked into single round containers (SRCs) and placed into crates holding up to 8 munitions. Overpacked munitions were moved to the isolation HWSU and then assessed.

1.4 Organization and Management Responsibilities

The principal organizations that participated in this project include PMNSCM, USAE ACWA, CARA, BGAD, BGCA, CMA SMO, and the BGCAPP FO. The primary organizations are presented in figure 1-2 and the onsite command and control organizations in figure 1-3; responsibilities during the assessment activities are described in the following paragraphs.

Project Manager for Non-Stockpile Chemical Materiel (PMNSCM)

PMNSCM had programmatic responsibility for ensuring that the assessment was accomplished in a safe and environmentally acceptable manner. The PMNSCM provided an onsite manager for oversight and management of all assessment activities. This onsite manager had authority to halt and/or resume activities at any point during assessment operations.

U.S. Army Element, Assembled Chemical Weapons Alternatives (USAE ACWA)

USAE ACWA has programmatic responsibility for destruction of chemical munitions stored at BGAD. USAE ACWA was responsible for the project sponsorship and provided program oversight, funding, cost estimation review, and technical input.

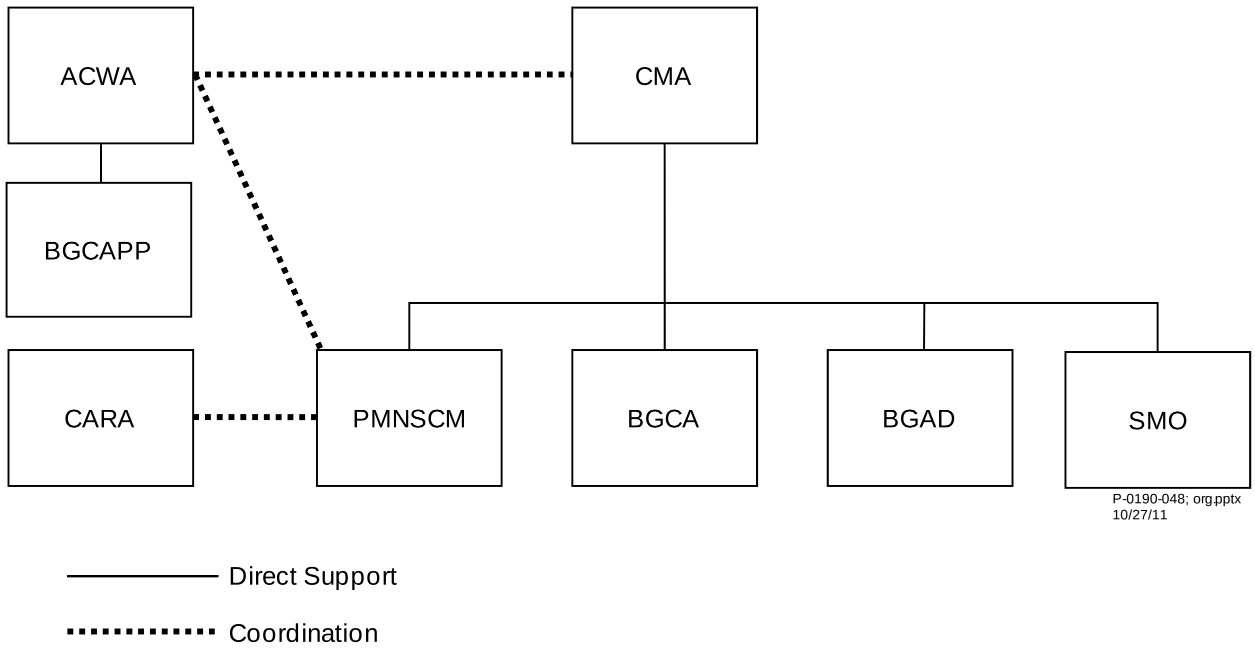


Figure 1-2. Organization for Munitions Assessment at BGAD

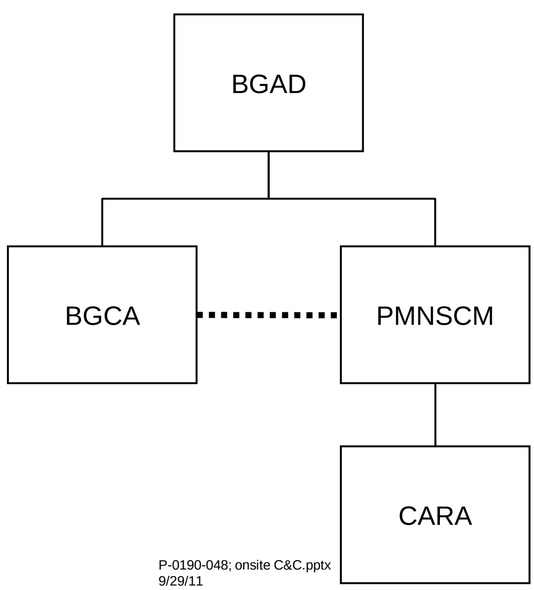


Figure 1-3. Onsite Command and Control

U.S. Army 20th Support Command Chemical, Biological, Radiological, Nuclear and High Yield Explosive (CBRNE), Chemical Analytical and Remediation Activity (CARA)

The CARA team developed a work plan for assessment activities and performed non-intrusive assessments using the Digital Radiography/Computed Tomography (DRCT) X-ray system. CARA exercised control of munitions during all assessment activities.

Blue Grass Chemical Activity (BGCA)

BGCA wrote and coordinated the review and approval of the work plan for chemical munitions external movement and X-ray assessment of mustard projectiles. During the assessment, BGCA coordinated site operations, performed overpacking and movement of munitions; assisted with setup and testing of the SRCs; and was responsible for monitoring during assessment activities. BGCA was also responsible for coordinating public outreach with the public and state regulatory agencies.

Blue Grass Army Depot (BGAD)

The BGAD mission is to provide munitions, chemical material surveillance, and special operations support to the Department of Defense (DoD). During the assessment, BGAD maintained control of the site at all times and was responsible for manning of the operation control post (OCP) and security.

U.S. Army Chemical Materials Agency Stockpile Management Office (CMA SMO)

CMA SMO provided coordination of all preparation planning, including the packing and transport activities. SMO tracked and scheduled all activities prior to X-ray operations and coordinated with all stakeholders involved.

Blue Grass Chemical Agent-Destruction Pilot Plant Field Office (BGCAPP FO)

BGCAPP FO provided a review of all planning documents, historical knowledge on the mustard stockpile, and an igloo-directed sampling approach. The BGCAPP FO is the end customer for use of this report.

1.5 Storage Environment

1.5.1 Specific Igloos. Stockpiled chemical munitions are stored on pallets in storage structures known as igloos, magazines, or earth-covered bunkers. The storage structures are inside the Chemical Limited Area (CLA). Igloos are designed specifically to store the chemical agent munitions and minimize any explosive event from propagating to other surrounding igloo-stored munitions. A secondary element of these igloos is to protect the chemical weapons from external factors such as high winds, lightning, and other weather-related events. The igloos are approximately 26.5 feet high, 15 feet wide, and 80 feet long. They are constructed of steel-reinforced concrete and capped with approximately 25 inches of soil. The front wall of each igloo consists of 10-inch thick, steel-reinforced concrete with a 3,000-pound vented concrete door. The structure is equipped with a rear vent and lightning protection.

During the assessment, the 96 projectiles were selected from three igloos: H01, H02, and H03; previously overpacked munitions were staged in HWSU H04.

1.5.2 Temperature Information. Air temperature data were collected inside the assessment igloo during assessment of the munitions. The most important reason for collecting the temperature data was to make certain that temperature in the igloo was above 58°F. Data acquired from previous air temperature studies by BGCA in 1999 and 2000 were used to determine sample locations within the igloo. In the current assessment, the Data Logger Thermometer HH309 was used to track the temperature at four locations within the igloo. Temperature probes were placed on three Simulation Equipment Test Hardware (SETH) 155mm projectiles that were configured similarly to that of the 96 sample projectiles. The three SETH items were located at the rear, middle, and front of the igloos; a fourth probe measured air temperature at the middle of the igloo. A description of the Data Logger Thermometer HH309 is presented in section 2.2.2.

According to the draft Noblis sampling plan, temperature fluctuations can influence the formation of mustard heels. Furthermore, it was reasoned that items stored near the igloo entrance could be exposed to greater fluctuations in temperature; therefore, they were expected to have more heel than those stored in the back of the igloo where temperatures were assumed to be lower. A statistical analysis and discussion of these assumptions are detailed in section 3 of this report.

SECTION 2
OPERATIONS

2.1 Sampling Strategy

The objective of the analysis presented in the Noblis sampling plan was to identify the number of samples needed to determine the presence and magnitude of heel in M110 155mm projectiles in storage at BGAD. The Noblis sampling plan in its entirety is presented in appendix B of this report (portions of the Noblis sampling plan were redacted for operational security considerations).

It was impractical to X-ray the entire BGCA stockpile of M110 155mm munitions. Therefore, the sampling plan proposed that a subset of the stockpile munitions be X-rayed. The subset should be as representative of the entire population as possible. This would normally mean that random sampling would be performed. However, random sampling of the munitions at BGAD was not realistic due to safety and environmental risks associated with handling the munitions. Therefore, a directed sampling approach was employed. The following factors were taken into consideration:

- The M110 H-filled 155mm munitions are stored in several storage igloos. Therefore, it was decided to select 32 munitions each from three different igloos, thus having a large enough sample that comparison can be made igloo to igloo.

- The munitions are banded onto pallets of eight munitions each. Therefore, it was decided for safety reasons to select whole pallets of munitions for X-ray examination rather than individual munitions.

- Within each igloo, the pallets of munitions are stored in 11 stacks. Pallets were selected to ensure an equal number of munitions from the front, middle, and back of each igloo.

- The munitions are divided into three lot numbers, but the distribution is not equal. Lot BGD-655-5 comprises 12 percent, Lot BGD-655-7 comprises 58 percent, and BGD-655-9 comprises 30 percent of the total number of 155mm munitions. It was not practical to duplicate this distribution among the munitions to be X-rayed. However, this distribution was fit as closely as possible given the limitation of munitions banded together in pallets of 8 each. Therefore, one pallet of eight munitions was selected from lot BGD-655-5 (8 percent of the samples). Seven pallets were selected from lot BGD-655-7 (57 percent of samples), and four pallets of eight munitions were drawn from lot BGD-655-9 (33 percent of samples).

Figure 2-1 shows the layout of 155mm projectiles in a storage igloo. Highlighted rectangles indicate the location of pallets that were sampled.

2.1.1 Factors Influencing the Sampling Plan. Numerous factors were considered during development of the sampling and work plans. These factors include munitions characteristics, storage characteristics, and statistical principles relating to heel occurrence and distribution.

2.1.1.1 Munitions Characteristics. While planners recognized that there were variations in the manufacturing dates (lot numbers) of the fill material and munitions parts, the assumption that these differences have an effect on heel formation has not been proven with certainty. Furthermore, the high degree of commonality in agent manufacturing lot numbers between the three BGCA lot numbers would tend to mask any actual differences that may exist between the manufacturing lots. Therefore, adjustments were not made to the sampling strategy based on these variations.

It was also recognized that temperature fluctuations over years of storage might influence heel formation. However, because the sampling event is only one point in time, it was not possible to directly assess this potential effect. However, if over the years there have been temperature differences between the storage igloos that were

Figure 2-1. Igloo Storage Layout and Locations of Pallets Sampled

large enough to influence heel formation, this should show up in a comparison of munitions from one igloo to another.

2.1.1.2 Storage Characteristics. Storage characteristics that influenced development of the sampling plan are identified in the following list:

- The munition lot numbers used at BGAD appear to be administrative in nature and do not represent meaningful groupings that are traceable to manufacturing, loading, or other significant events that might relate to heel formation.

- Stacking of munitions on pallets and storage configuration limited accessibility to the individual munitions.

- Random sampling was not realistic due to safety considerations. To produce a truly random sample, the amount of re-warehousing required to pull out randomly selected munitions was judged to pose too great a safety hazard to workers. The hazards included potential exposure to chemical agent and general safety hazards from working around forklifts and heavy pallets. Every time a munition is handled, there is a potential that a leaker will be created, thus potentially exposing workers to chemical agent. The act of re-warehousing the munitions exposes workers to potential slips, trips, and falls as well as the potential of being pinched or pinned between two objects. Therefore, directed sampling was performed resulting in a total of 12 pallets of 8 munitions each being drawn from the front, middle, and back of the sampled storage igloos.

- Operational constraints (limits on funding, manpower, and equipment required for handling the munitions and re-warehousing needed to draw the samples from the stockpile).

2.1.1.3 Statistical Considerations. Statistical considerations primarily involve the degree of confidence and accuracy desired by decision-makers, the amount of variability that exists between individual munitions, and the actual quantity of heel that may be problematic when all is said and done.

The Noblis sampling plan provided a range of sample sizes each representing a different combination of confidence and accuracy. Planners could then apply trade-offs of safety, cost, and time to reach a decision as to the sample size that would be used. Factors entering into statistical consideration include:

- Variation in the presence of mustard heel is a driving factor in determining the sample size. If all munitions had exactly the same amount of heel, then only one munition would need to be X-rayed to determine heel, percentage for all the munitions. The more variability there is between munitions, the larger the sample size needed.

- The distribution of heel percentages also influences the sampling plan. There are numerous distributions that could be experienced, such as a normal distribution, a X^2 distribution, or a bimodal distribution to name three. Each distribution carries its own set of implications for the sampling plan. Therefore, planners must use available information to make assumptions about what is likely to be found and design the sampling plan as best as possible to accommodate the possibility that the assumptions were not correct.

After evaluating these factors, Noblis prepared a statistically based sampling plan that incorporated as much as possible the trade-offs between a larger sample size with its added expense in time, money, and risk to workers and a smaller sample size with its risk of not collecting sufficient data to accurately characterize the BGCA stockpile. Sampling size approaches provided in Military Standard (MIL-STD)-105E and MIL-STD-1916 were considered along with other standard statistical sampling approaches, including those designed for binomial distributions, normal distributions, and Poisson distributions.

2.1.2 Summary of Statistical Basis. One obstacle to the development of the sampling plan for BGAD is that there was no prior knowledge about heel amounts in the BGAD munitions. Consequently, Noblis looked at heel data obtained from similar munitions that had been stored at Deseret Chemical Depot (DCD). The DCD heel data consisted of 10 samples where percent solids had been measured. The DCD data were examined and found to fit a normal distribution. Therefore, it was assumed that heel percents in the BGAD munitions would also follow a normal distribution.

The question of whether the amount of heel in the BGAD munitions will pose a problem for the planned demilitarization operations lends itself to a binary solution. That is, either the amount of heel in a given munition is going to be a problem or it is not. With no prior knowledge of how much heel would pose a problem, it was assumed by the project team that 50 percent heel was the dividing line between being a problem and not being a problem.

In order to determine the number of samples required to achieve a given level of confidence, Noblis calculated sample sizes for various assumed probabilities and confidence levels. For example, what is the sample size needed at 90 percent confidence to determine if the probability of a munition having ≥50 percent heel is 0.5? What is the sample size needed if the probability is 0.1 or 0.9? This is a reasonable approach given that there was little knowledge of the existence and quantity of heel in the BGAD munitions.

Six different sample sizes were calculated representing different combinations of accuracy and confidence. The sample sizes ranged from 41 samples for an accuracy of ±10 percent and 80 percent confidence to 384 samples for an accuracy of ±5 and 95 percent confidence. A sample size of 96 was obtained for an accuracy of ±10 percent and a confidence of 95 percent. This sample size (96 samples) was a compromise between the expense in time and money and potential worker safety to obtain data from more samples and the small added benefit given by the additional data. Furthermore, an accuracy of ±10 percent and 95 percent confidence are frequently used, especially for a sampling event when rather little is known about the population being sampled. It was planned that if the first sampling event identified something peculiar about the population, a second sampling event could be performed to examine the peculiarities in greater detail.

Due to all these considerations, the directed sampling approach, recommended by the BGCAPP FO, was that in each igloo from which samples would be drawn, 4 pallets of 8 munitions would be selected, giving a total of 32 munitions per igloo. In order to assess the assumed influence of location on heel development, the igloos were divided into front, middle, and rear sections with one pallet being taken from each section. The fourth pallet would come from the front of one igloo, the middle of the next, and the rear of the third igloo.

2.2 Assessments

In the winter prior to the commencement of X-ray examinations, BCGA had gone into the storage igloos, identified the munitions to be examined, removed them from their storage locations, visually inspected and photographed them, noting any anomalies such as lifting ring problems, rust, or illegible markings. The inspection also included confirmation or denial that "EA" was stamped on each round. After inspection was complete, the munitions were placed inside of foam inserts and overpacked inside SRCs. The SRCs were packaged into crates and moved from the storage igloo to the assessment igloo, which would become their new storage location. Appendix F contains a description of the overpacking process and photographs showing the overpack, the foam core, and selected munitions with their associated overpacks. This work was performed in the winter when the mustard agent is frozen to minimize the risk of workers being exposed to chemical agent and of releasing agent to the environment.

Visual inspection found that none of the munitions were stamped or embossed with EA markings, and none of the munitions were found to have lifting lug anomalies.

Inspection did identify six munitions with rust or illegible painted marking. Appendix F contains photographs of these six munitions. The anomalies noted include:

- Munition #1: Marking illegible and some rust present
- Munition #10: Minor rust present
- Munition #20: Minor rust present
- Munition #25: Markings illegible and heavy rust present
- Munition #29: Markings illegible and heavy rust present
- Munition #70: Minor rust present.

Between 9 May and 14 June 2011, X-ray assessments were performed by CARA personnel on 96 stockpiled munitions (12 pallets x 8 munitions) using the DRCT system. The 96 munitions contained bursters, but no fuzes. Based on historical knowledge, fill levels were expected to range from 80 percent to 90 percent. An 80-percent fill level was chosen for use in assessment calculations.

X-rays and associated materiel assessment data sheets (MADS) of each of the assessed munitions are included on the enclosed CD (Appendix E, X-ray Images). Data of each sample from the assessments are consolidated (Excel® spreadsheet format) and are available in appendix C and the enclosed CD as well. For each sample, information is presented identifying the sample (sample number, lot number, magazine number, and location within the magazine). Results for each munition assessed include the measured liquid fill and estimated percent heel, as well as an interpretation of the calculations, descriptions of what was seen in the X-rays, and collected temperature data. Statistical results are presented in section 3.

2.2.1 CARA Procedures. In addition to performing the X-ray examinations, CARA operators were to record and attempt to identify any anomalies seen in the X-rays that might be predictive of difficulties in removing the burster well. CARA operators participated in handling and movement of the sample munitions before, during, and after assessment.

During assessment, specific CARA procedures included securing the sample item to the X-ray platform; remotely performing and monitoring scans from the CARA Command Post (CP); repositioning the sample item as necessary between scans; assisting in determination of X-ray data acceptability; removing the sample item from the X-ray platform; and returning the item to the respective storage pallet.

Each of the 96 sample munitions was X-rayed in the inverted (nose down) position. The munitions are normally stored in a nose-up position. Therefore, X-raying them in an inverted position made distinguishing solid from liquid easier. Liquid would collect in the nose end of the agent cavity while the heel would remain in the bottom end of the munition. This allowed for very accurate measurement of the liquid level, which was then used to calculate heel percentage by subtracting the liquid amount from 80 percent.

2.2.2 Equipment and Instrumentation.

2.2.2.1 Digital Radiography and Computed Tomography (DRCT) System. The DRCT system is a field-portable system used to X-ray recovered chemical warfare materiel. The system uses an X-ray to vertically scan the chemical munition on a rotating platform to produce a digital view of the munition's interior. These images can be analyzed to determine if the munition contains liquid fill or heel and if a fuze and/or burster is present. Using a computer, the operator can remotely control all scanning and data collection operations.

The non-intrusive (X-ray) analysis examined whether sample munitions contain only liquid agent or a mixture of liquid and solids (heels), and provided data for calculating the percentage of heel present. X-ray images and data of each sample munition are included in appendix E (the CD); examples of the X-rayed images are presented in figures 2-2 through 2-5.

Software developed by Idaho National Laboratory (INL) was used to calculate the amount of liquid fill and percentage of heel. The depth of liquid fill was measured on the

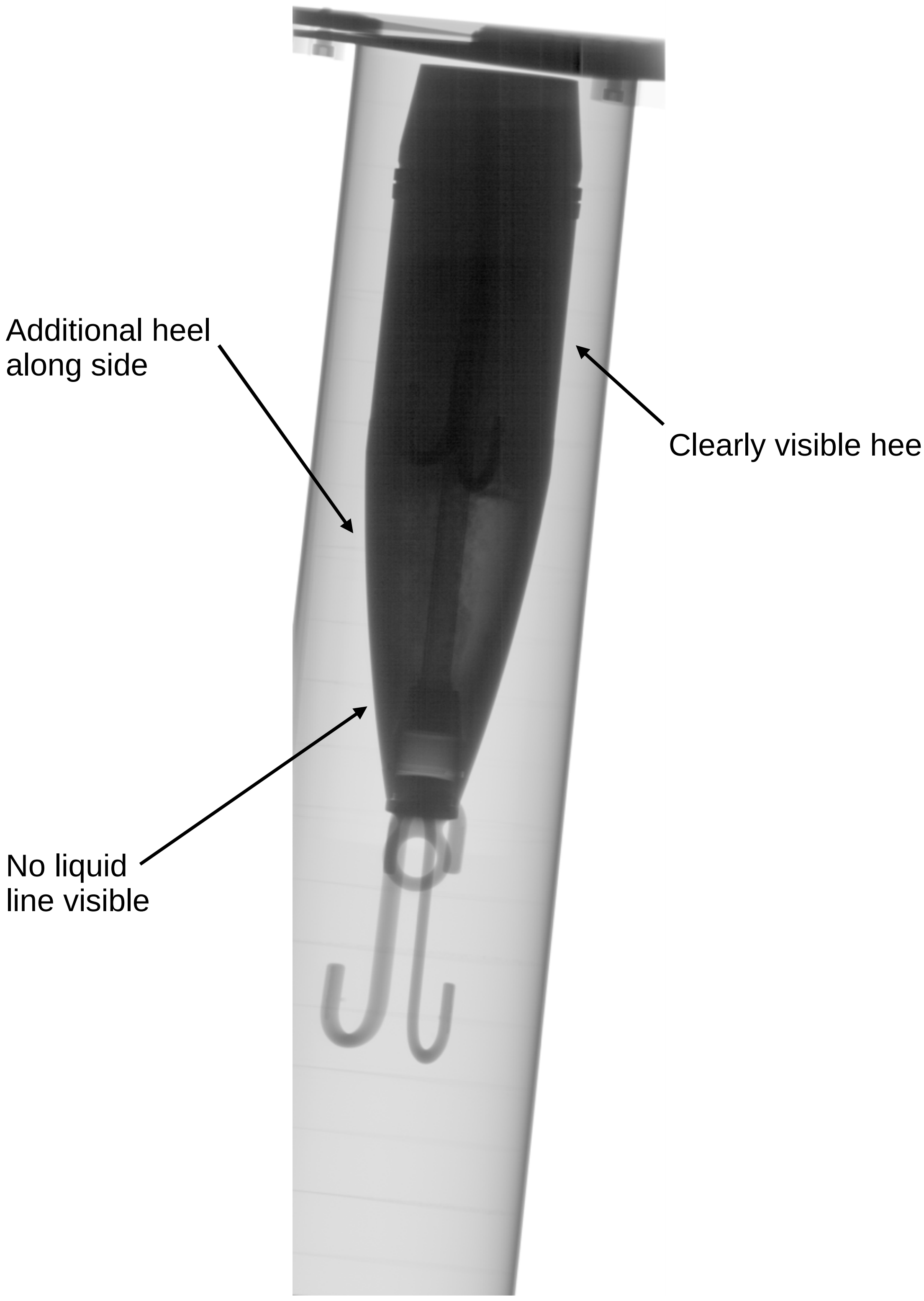


Figure 2-2. BGX-02-002, 155mm Projectile, 80 Percent Heel

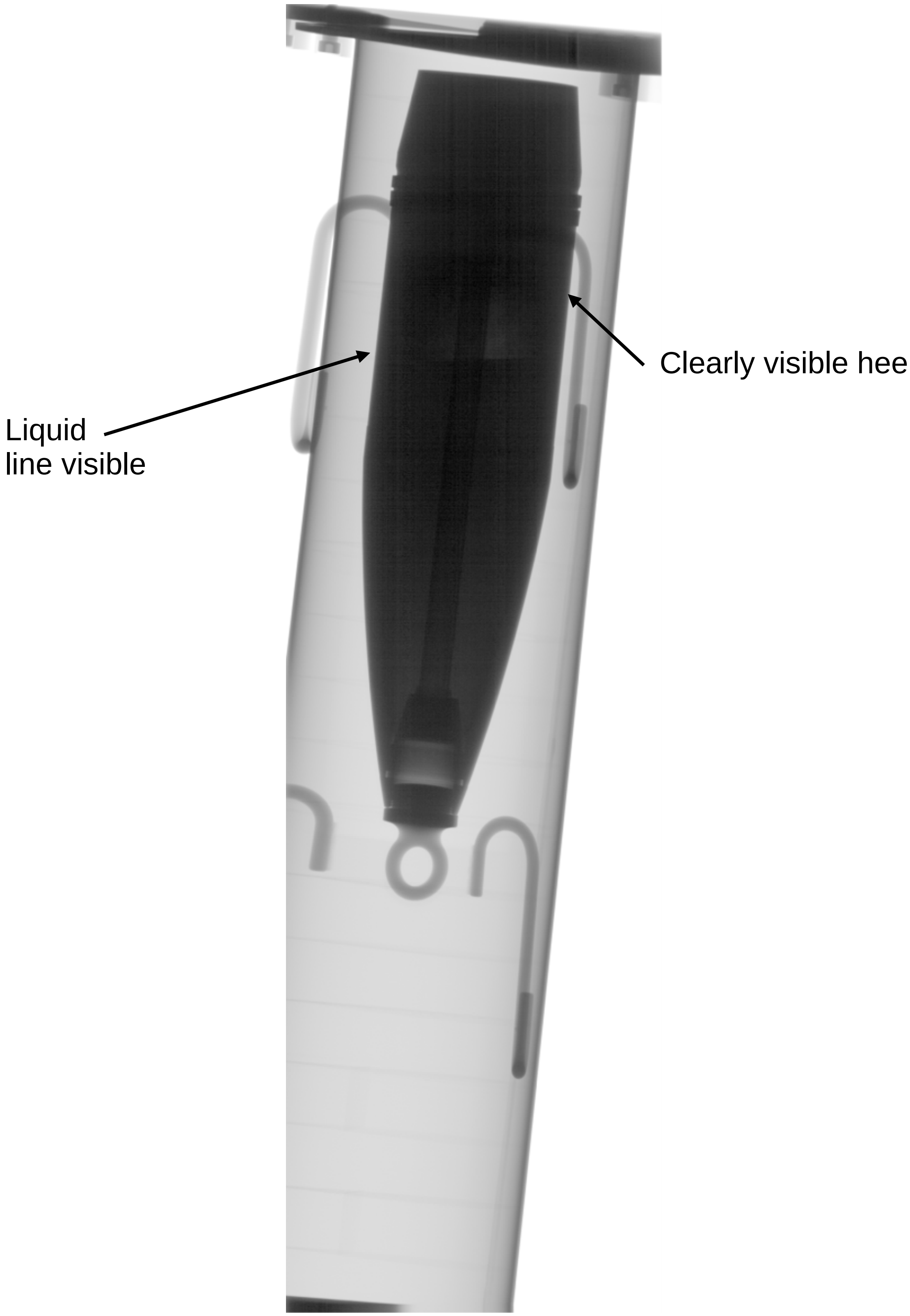


Figure 2-3. BGX-02-003, 155mm Projectile, 17.1 Percent Heel

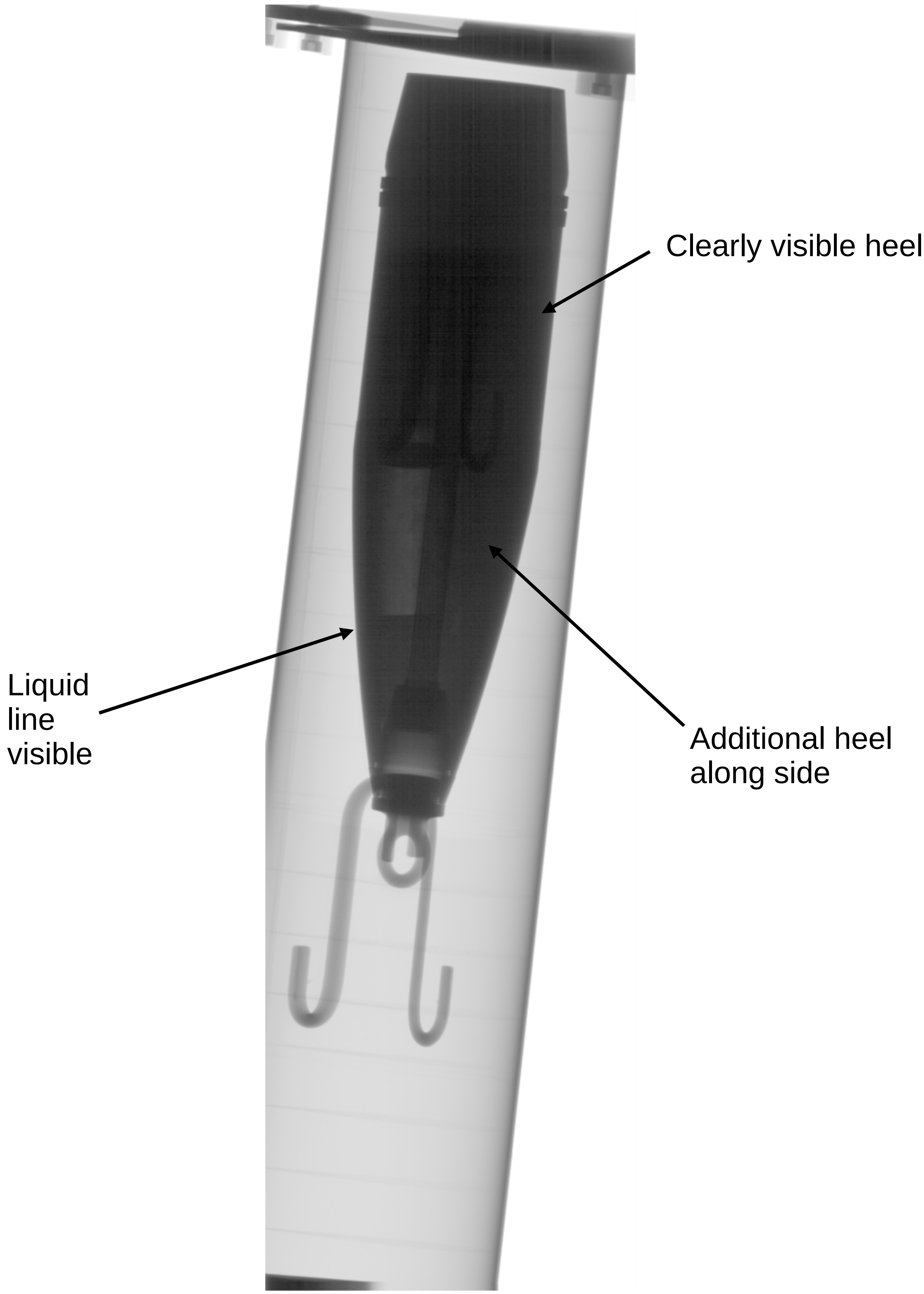


Figure 2-4. BGX-02-008, 155mm Projectile, 71.2 Percent Heel

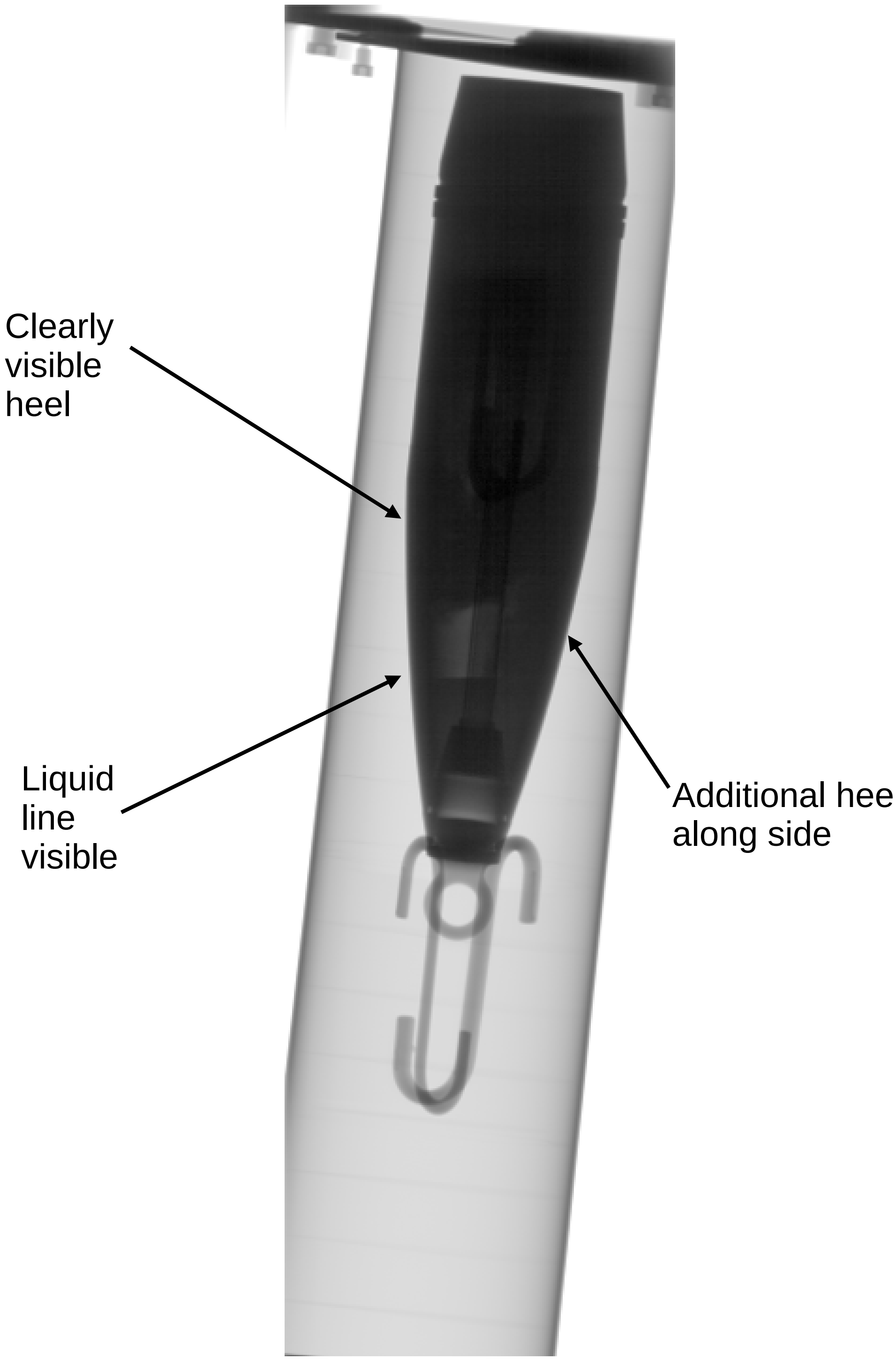


Figure 2-5. BGX-02-013, 155mm Projectile, 72 Percent Heel

X-ray and that value entered into the program. The software calculated the percentage of the agent cavity filled with liquid based on the geometry of the agent cavity. The amount of heel present was calculated by subtracting the percentage of liquid fill measured from 80 percent, the assumed munition fill level.

2.2.2.2 Data Logger Thermometer HH309. The Data Logger Thermometer HH309 was used to track the temperature at four locations within the assessment igloo. This instrument is a four-channel digital thermometer plus a powerful data logger for use with any K-type thermocouple as temperature sensor.

The internal memory unit can store up to 16,000 records per channel at programmed intervals. It uses an RS232 interface to perform bi-directional communication with a personal computer. Temperature indication follows the National Bureau of Standards and IEC584 temperature/voltage table for K-type thermocouples.

The JME Portable 2.5 MeV X-Ray Betatron was used for radiographic non-destructive assessment of the munitions. It is a portable, compact, circular electron accelerator producing a high energy directional X-ray beam. The Betatron is used at external sites and produces radiographs of high contrast, sensitivity, and resolution.

2.3 Previously Overpacked Munitions Assessment

X-ray examination was performed on 80 munitions previously overpacked and identified as “leakers.” The previously overpacked munitions were X-rayed in an upright orientation to avoid potentially causing more leakage from being in an inverted position. Previously overpacked munitions were assessed in igloo H04 to better characterize their condition. Figures 2-6 and 2-7 are X-rays of previously overpacked munitions.

Each of these munitions had been identified as leaking or having some other problem discovered during long-term storage, which necessitated its removal from the general population of stockpile munitions. Such munitions are overpacked at the time they are identified and moved to a separate storage area commonly referred to as the leaker igloo.

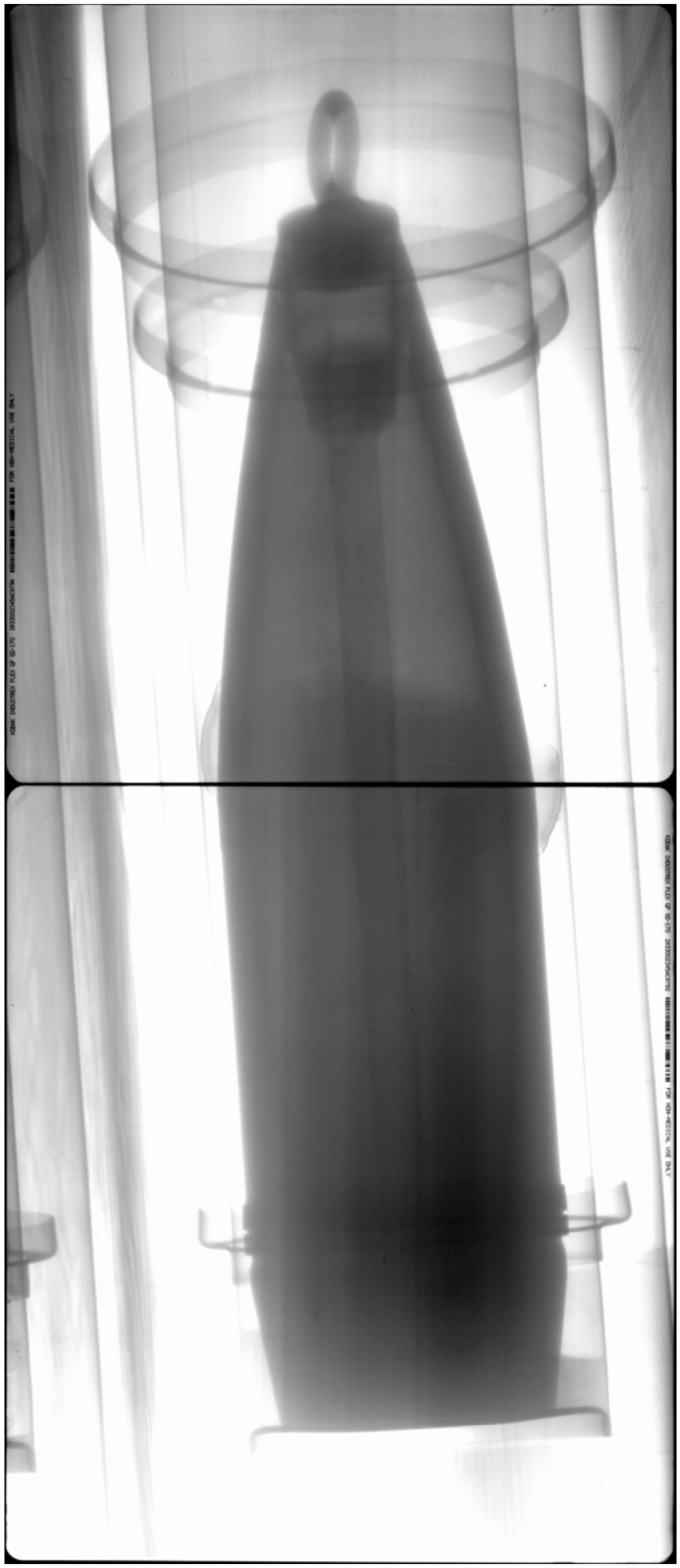


Figure 2-6. BGX-02-161, 155mm Projectile, 80 Percent Heel

Figure 2-7. BGX-02-141, 155mm Projectile, 20 Percent Heel

SECTION 3
RESULTS

3.1 Heel Data

The sampling plan called for collecting heel data on 96 munitions distributed between the front, middle, and rear of the sampled magazines. In addition, seven repeat X-rays at different times from the initial X-ray were taken to evaluate reproducibility of the measurement method and to determine if warmer temperatures at the end of the assessment period would have a significant effect on the amount of heel observed.

Temperature data collected at the time of the X-ray examination indicated that the air temperature in the assessment igloo ranged from 70.5°F to 72.5°F. The lowest temperature recorded on one of the SETH munitions (inside the overpack) was 66.1°F. Therefore, the temperature of the munitions at the time of X-ray was above the freezing point of mustard agent. This means that any solid material observed on the X-ray of the agent cavity was heel rather than frozen mustard agent.

For the 96 samples, heel was not measured directly; rather, it was calculated from liquid level. Heel typically has an uneven surface that can be difficult to measure on an X-ray, whereas a liquid line is level and easily distinguished.

Chemical munitions are stored in a nose-up orientation. Therefore, heel, if present, should have formed at the base of the munition. To measure the liquid fill level, the munitions were inverted so any liquid would flow to the nose of the munition, producing a clear liquid level in the X-ray. Software was used to calculate the amount of liquid present in the munition based on the depth of liquid seen in the X-ray. Heel was then calculated by subtracting the amount of liquid from the assumed munition fill level. No original agent fill amount could be 100 percent accurately established for the individual munitions. Therefore, an assumption was made based on historical information about filling practices for the 155mm projectile. It was assumed that all munitions had originally been filled to 80 percent of the volume of the agent cavity.

Heel data are reported in terms of the presumed 80 percent fill. Consequently, if no liquid agent was identified in the X-ray, the heel level was reported as 80 percent; if the liquid fill was observed as 50 percent of the volume of the agent cavity, the heel level would be reported as 30 percent (80 – 50 = 30).

It was observed in some of the X-rays that heel was evident along the side of the agent cavity, indicating that the munitions had been stored on their sides at some time in the past. This observation is consistent with what is known about how munitions were stored during the 1940s and 1950s. At that time, bulk munitions were stored as loose items lying on their sides with blocking at the ends of the rows rather than as upright items banded on pallets as they are now.

Historical records indicate that when the munitions arrived at the depot, the entire inventory of H projectiles was stored outside in a horizontal configuration. In the 1950s, when the munitions were assigned to three “BGD” lots, the original EA lot quantities were lost, although the original lot numbers are known. The method for determining which BGD lot a munition was assigned to was called “zone weight” whereby the weight of the agent fill in each munition was determined by weighing the munition and subtracting the average weight of an empty munition.

The original EA lots would have been separated by zone weight and comingled with other EA lots having the same zone weight. The stockpile was moved inside igloos at some point. Later, perhaps in the 1970s, the rounds were moved to their current igloos. Throughout their storage life, they have been moved within the igloo to find leakers and often returned to different locations within the same igloo. When a leaker was removed from an eight-round pallet, the pallet was rebanded as a six- or seven-round pallet that had to be stored in a top location. This resulted in an unknown amount of mixing of pallets and rounds; as a result, the stockpile is most likely a mixture of the original EA lots comingled together. For this reason, the population is pretty much homogeneous from igloo to igloo; therefore, the sampling plan takes a reasonable approach considering identified concerns and objectives.

3.1.1 Data Quality. Of the 96 initial X-rays taken, one sample (BGX-02-016) did not produce useable heel data because an indistinct liquid level in the X-ray made it difficult to calculate heel level. There was a liquid level (so the fill was not entirely heel), but the liquid level did not appear to extend all the way across the agent cavity. Field notes indicated that heel may have been sliding down the side of the cavity, making it impossible to obtain an accurate liquid level measurement. The problem encountered with sample BGX-02-016 did not occur when the munition was re-X-rayed later in the project (sample BGX-02-016A). Therefore, for calculation purposes, sample BGX-02-016A was substituted for sample BGX-02-016.

In addition to the initial X-rays, eight repeat X-rays were taken to assess reproducibility. One of the repeat X-rays was of the sample for which no initial data was reported (BGX-02-016). Therefore, seven repeat X-rays were found acceptable for assessing reproducibility of heel measurements. The repeat assessment of sample BGX-02-016 was substituted for the missing initial data in statistical comparisons.

3.1.2 Data Evaluation. Heel data have been evaluated in the following comparisons:

- General description of results (all data considered to be a single data set)
- Assessment of heel data based on magazine where the munitions are located
- Assessment of heel data based on location within each magazine
- Assessment of heel data based on lot number.

3.1.3 Entire Heel Data Set. The data as a whole were examined to determine mean and standard deviation as well as to determine if the data follow a normal distribution. The overall statistics are as follows:

- Number of initial data points = 96
- Mean = 54.8 percent
- Standard deviation = 20.5 percent
- Median = 51.4 percent
- Assumed fill = 3,300 milliliters (mL) (80 percent of agent cavity not occupied by the burster).

The volume of the agent cavity of a 155mm M110 shell was determined by INL (INL, undated) by filling the agent cavity of a SETH munition with a material such as sand or water, then pouring the material out and measuring its volume. This method determined the volume of the agent cavity to be 4,125 mL when the burster was present. This value (4,125 mL) was used to determine the volume of heel in the X-rayed munitions.

Therefore, the observation that the average percent heel is 54.8 percent equates to approximately 2,260 mL of heel. Likewise, the median percent heel of 51.4 percent equates to 2,120 mL of heel. Table 3-1 shows approximate volume and depth values for various percentages of heels.

Values in table 3-1 were calculated assuming that the 155mm projectile with burster has a volume of 4,125 mL within the agent cavity. Therefore, the volume of fill is calculated by multiplying the total volume by the percentage of heel (4,125 mL x 80% = 3,300 mL). Heel depth was approximated by assuming an average diameter of 9.7 centimeters (cm) for the agent cavity. This diameter was based on the diameter at 40 percent fill.

Table 3-1. Volume and Depth of Heel for Various Percentages of Heel

Percentage of Heel	Volume (mL)	Depth (cm)
10%	413	6
20%	825	12
30%	1,238	19
40%	1,650	25
50%	2,063	31
60%	2,475	37
70%	2,888	44
80%	3,300	50

Notes:

cm = centimeter
mL = milliliter

Depth was then calculated from the equation for volume of a cylinder (volume = pi x radius squared x height). The agent cavity is not a true cylinder; rather, it has a truncated conical shape at the bottom of the agent cavity. Therefore, the depth value calculated assuming a cylinder is somewhat generous when there is less than 40 percent heel and somewhat short when there is more than 40 percent heel. However, the discrepancies are considered inconsequential when it is taken into account that the heel is not a uniform depth across the width of the agent cavity. Some X-rays even showed heel along the side of the agent cavity, indicating that munitions had likely been stored on their sides at some point in time.

Heel values were grouped in 10 percent increments. That is heel values of 0 to <10 percent were in the first group, 10 percent to <20 percent in the second group, and so on to the last group, which represented munitions with 80 percent heel. This facilitated graphic depiction of the data. Table 3-2 shows how many of the 96 X-rayed munitions fell into each group.

Table 3-2. Heel Percentage Found in 96 X-rayed Munitions

Percentage of Heel	Number of Munitions	Percentage of all Munitions
0% to <10%	0	0%
10% to <20%	3	3.1%
20% to <30%	11	11.5%
30% to <40%	15	15.6%
40% to <50%	17	17.7%
50% to <60%	7	7.3%
60% to <70%	7	7.3%
70% to <80%	18	18.8%
80%	18	18.8%
Total	96	100%

Figure 3-1 shows the data in table 3-2 in a histogram. The histogram highlights the fact that for the 96 items X-rayed, heel distribution does not follow a normal distribution. Rather, heel percentage has a bimodal distribution with one peak at 40 percent to 50 percent heel and a second peak at 70 percent to 80 percent heel.

In figure 3-2, the data were classified into four groups instead of nine, as in figure 3-1. Munitions with 0 to <25 percent heel are represented in the first group. Munitions with 25 percent to <50 percent heel are represented in the second group, and so forth.

Figure 3-2 shows that slightly greater than 50 percent of the munitions have 50 percent heel or greater.

3.1.4 Implications for Blue Grass H-Filled 155mm Munitions. Based on the observed heel percentages in the 96 munitions that were X-rayed, an estimate can be made of what the average heel percentage is for the entire stockpile of H-filled 155mm munitions.

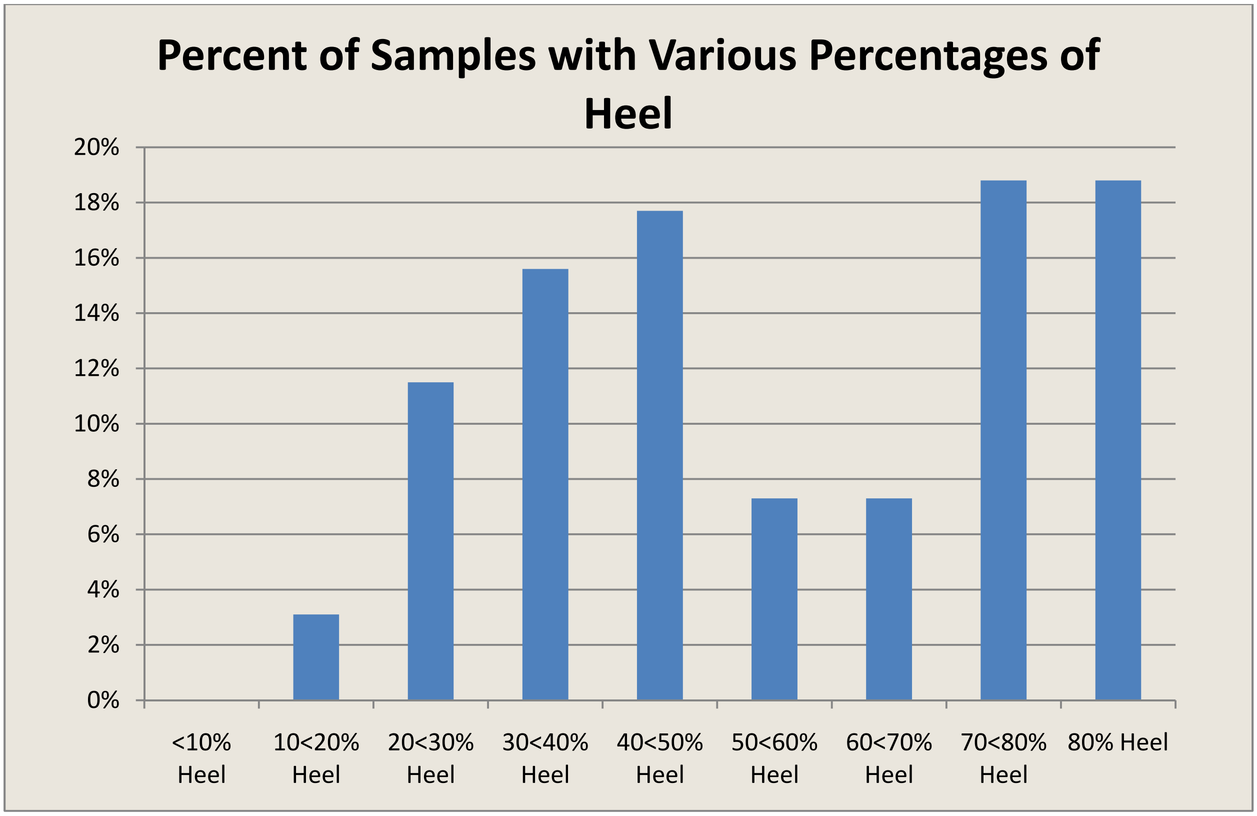


Figure 3-1. Heel Percentages in 96 X-rayed Munitions

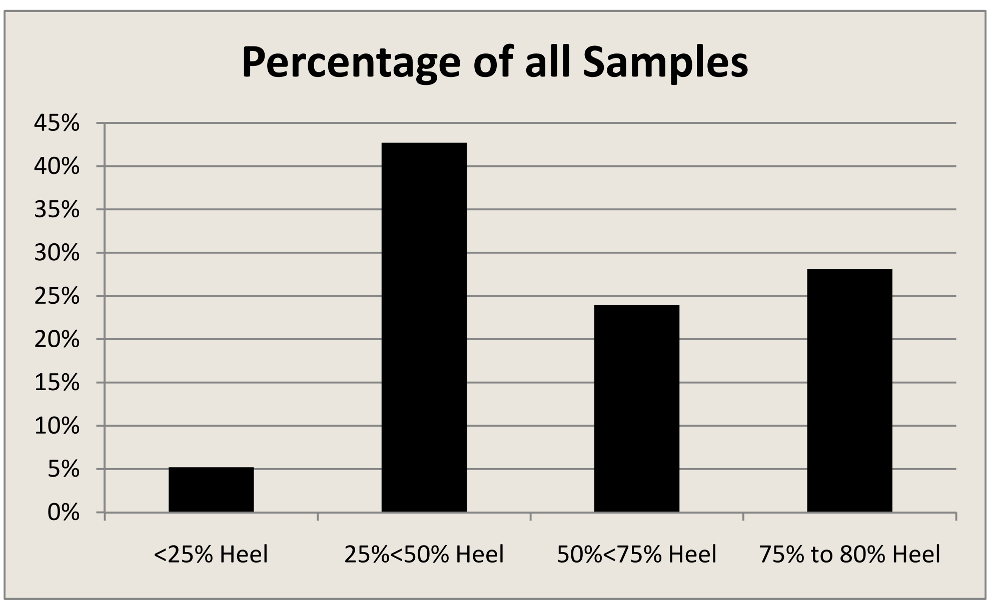


Figure 3-2. Percentage of Heel Divided into 4 Classes

The sample data can be used to calculate confidence limits that express the upper and lower limits for the mean heel percentage for all of the H-filled 155mm munitions. The upper and lower confidence limits are calculated based on the mean, standard deviation of the samples, the number of munitions X-rayed, and a desired level of confidence. The 96 munitions X-rayed had a mean heel percentage of 54.8 percent and a standard deviation of 20.5 percent. Applying a 95-percent confidence interval, the upper and lower confidence limits for the average heel percentage of the entire stockpile would be 59.0 percent and 50.6 percent. The margin of error is 4.2 percent. This means that there is 95 percent confidence that the true mean heel percentage for all of the H-filled 155mm munitions is between 50.6 percent and 59 percent. Figure 3-3 shows the number of munitions (vertical axis) that may be expected to have various percentages of fill converted to heel (horizontal axis). In figure 3-3, 100 percent means that 100 percent of the fill has been converted to heel.

3.1.5 Comparison by Magazine. The munitions X-rayed were drawn from three different magazines. The data were examined to determine if there was a difference in percent heel between magazines. Table 3-3 contains a summary of data by magazine, and figure 3-4 depicts the average heel percentages by magazine in a histogram.

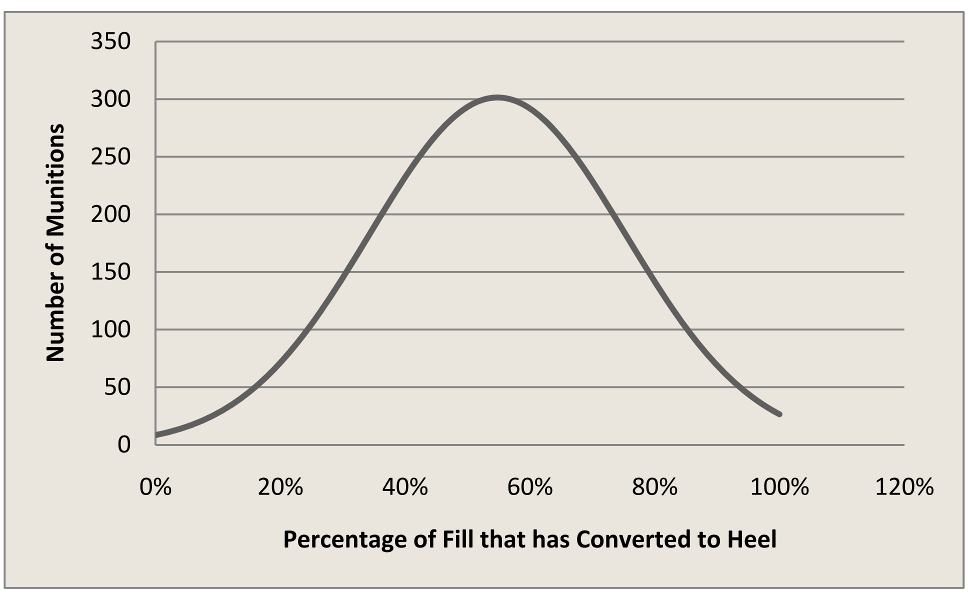


Figure 3-3. Number of Munitions by Percent Heel

Table 3-3. Comparison by Magazine

Parameter	Magazine H01	Magazine H02	Magazine H03
Number of samples	32	32	32
Mean heel percent	54.8%	48.4%	61.1%
Standard deviation	19.6%	19.6%	20.8%
Normal distribution	Yes	No	No

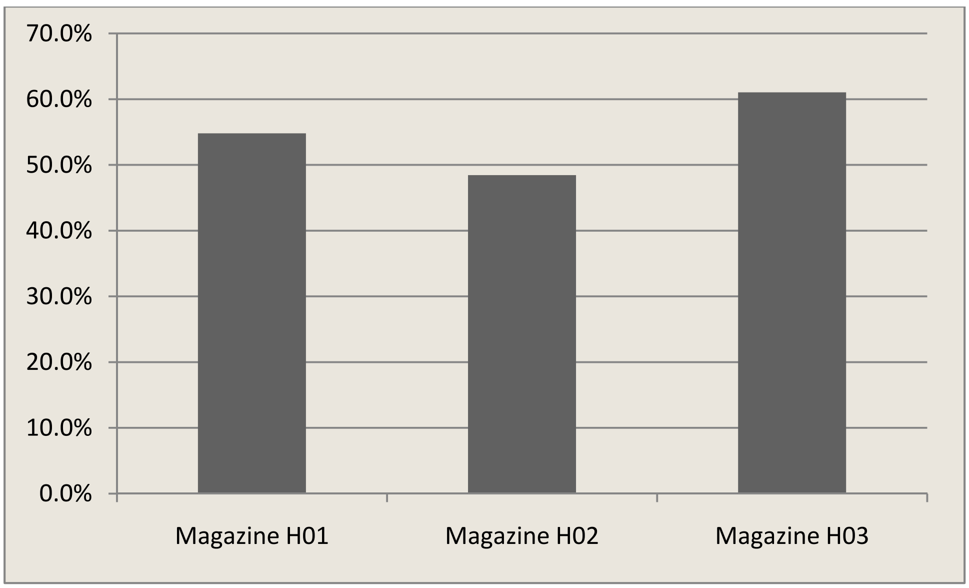


Figure 3-4. Average Percent Heel by Magazine

Because not all the data fit a normal distribution, the Mann-Whitney U-test was used to compare the data from one magazine to another. The differences in heel values from one magazine to another were not statistically significant in any of the possible comparisons (magazine H01 vs. H02, magazine H01 vs. H03, or magazine H02 vs. H03).

3.1.6 Comparison by Location Within a Magazine. Heel data for munitions in the front, middle, and rear of the magazines were compared to see if there were differences in amount of heel based on location within the magazine. Table 3-4 presents a summary of heel data by location.

Each magazine may contain up to 11 stacks of munitions. Therefore, the working definition of front was set as measurements of munitions in stacks 1, 2, or 3 (24 measurements). Middle was represented by munitions in stacks 5, 6, and 7 (32 measurements); and back was represented by munitions in stacks 9, 10, and 11 (32 measurements). The reason that the front location (stacks 1, 2, and 3) had fewer measurements than the middle or back locations is that there were 8 measurements taken of munitions in stack 4. Since that location is outside the definition of front or

Table 3-4. Percent Heel by Location Within Magazine

Parameter	Rear	Middle	Front (without Stack 4)	Total (without Stack 4)	Front (with Stack 4)	Total (with Stack 4)
Number of measurements	32	32	24	88	32	96
Mean	59.2%	52.5%	48.0%	53.7%	52.6%	54.8%
Standard deviation	21.5%	19.9%	18.6%	20.4%	19.9%	20.5%
Normal distribution (K-S test $\alpha = 0.05$)	No	No	Yes	No	No	No

Note:

K-S = Kolmogorov-Smirnov

middle, those measurements were not included in the initial location comparison. Excluding data from stack 4 left a total of 88 data points for consideration.

After performing the initial evaluation of location within the magazines, the data for munitions in stack 4 were added to the definition of the front location in order to make the numbers of data points equal in each of the three locations.

The Kolmogorov-Smirnov ($\alpha = 0.05$) and the Shapiro-Wilk ($p = 0.05$) tests for normality were used to determine if the heel data were normally distributed. Only data for the samples taken from the front of the magazine (excluding stack 4) followed a normal distribution. Because not all the data were normally distributed, the non-parametric Mann-Whitney U-test for independent data was used to compare the sampling locations.

Comparison of heel levels in the rear to the middle indicated that the difference was not significant. Comparison of the rear to front without using the data from stack 4 indicated a marginally significant difference. However, when the stack 4 data were included in the values for front, the result was that there was no significant difference between front and rear at $P = 0.05$.

3.1.7 Comparison by Lot Number. The munitions X-rayed represent three different lot numbers. The number of munitions sampled by lot number approximated the percentage of all munitions in each lot number. Table 3-5 summarizes the data by lot number. Figure 3-5 depicts the mean percent heel by lot number in a histogram.

3.1.8 Comparison of Initial and Repeat Heel Measurements. There were seven repeat heel measurements performed resulting in seven usable data pairs for comparison of initial versus repeat measurement.

Table 3-6 shows the initial and repeat data pairs. The differences between initial and repeat measurements are also shown. As might be expected from inspection of the

Table 3-5. Summary of Percent Heel by Lot Number

Parameter	Lot BGD-655-5	Lot BGD-655-7	Lot BGD-655-9
Number of samples	8	55	32
Mean heel percent	44.2%	52.3%	61.1%
Standard deviation	23.4%	19.1%	20.8%
Normal distribution	No	No	No

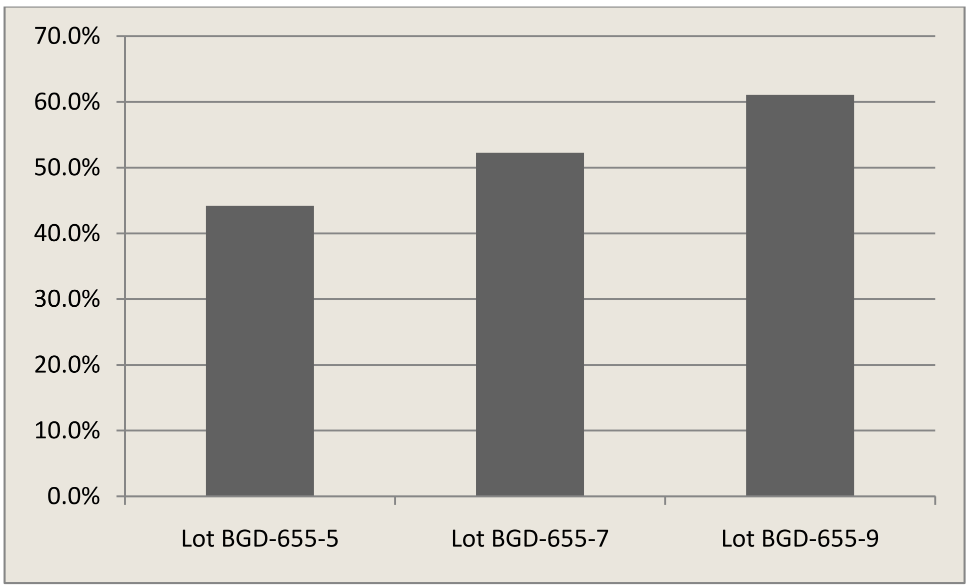


Figure 3-5. Average Percent Heel by Lot Number

Table 3-6. Initial and Repeat Heel Measurements

Samples	Initial Heel Percent	Repeat Heel Percent	Difference
BGX-02-009 and -009A	65	69.2	4.2
BGX-02-013 and -013A	72	66.3	-5.7
BGX-02-032 and -032A	80	80	0.0
BGX-02-043 and -043A	80	80	0.0
BGX-02-044 and -044A	76.4	75.1	-1.3
BGX-02-048 and -048A	70.8	69.6	-1.2
BGX-02-029 and -029A	80	80	0.0
Average	74.9	74.3	-0.6
Standard deviation	5.8	5.9	

data, the difference from initial heel measurement to repeat heel measurement is not statistically significant.

3.2 Temperature Data

Temperature data were collected on SETH munitions placed in the rear, middle, and front of the magazine. Temperature data were also collected from the interior of the Earth Covered Magazine (ECM). Each time a munition was assessed, temperature readings were recorded.

3.2.1 Temperature Data Quality. Ninety-six initial measurements and 8 repeat measurements were made for a total 104 possible temperature measurements at each location.

3.2.1.1 Rear Data (SETH Temperature). Of the 96 initial samples, 9 data points (samples BGX-02-001 through -009) were rejected for statistical evaluation due to a problem with the data logger that resulted from a thunderstorm. Temperatures shown with an asterisk in the raw data were taken from the “nearest available temperature” to the actual assessment time. Because 9 temperature readings were rejected for quality control purposes, only 87 temperature measurements were evaluated.

3.2.1.2 Middle Data (SETH Temperature). Of the 96 initial samples, 9 data points (Samples BGX-02-001 through -009), all with asterisks, were rejected for statistical evaluation, leaving 87 temperature measurements for evaluation.

3.2.1.3 Front Data (SETH Temperature). Of the 96 initial samples, 9 data points (Samples BGX-02-001 through -009) were rejected for statistical evaluation, leaving 87 temperature measurements for evaluation.

3.2.1.4 Interior of ECM Data (Air Temperature). Of the 96 initial samples, 9 data points (Samples BGX-02-001 through -009) were rejected for statistical evaluation, leaving 87 temperature measurements for evaluation. An additional 10 samples (BGX-02-028 through -031, -042, and -044 through -048) were rejected because no temperature value was recorded due to the temperature sensor (or data logger) being off-line (denoted by an “OL” in the raw data), leaving 77 data points for evaluation in the interior of the ECM.

Data were checked for normality. After inspection of the data, the Kolmogorov-Smirnov test for normality was used to determine if the temperature data fit a normal distribution. A value of $\alpha = 0.05$ was used for the calculation. SETH temperature data for the rear and front were found to follow a normal distribution while the SETH temperature data for the middle and air temperature data for the interior of the ECM were not normally distributed.

Because not all the data were normally distributed, the signed rank test for paired samples was used for comparison of means. A paired sample t-test was performed for an additional comparison of means between the two data sets (rear and front) that followed normal distributions.

3.2.1.5 Quality Control Samples. Eight samples were repeated, providing a second set of temperature data. Of the eight repeated samples, one pair had an asterisk (*) on the initial data point (BGX-02-009). Of the remaining seven pairs of data, the temperature value for the repeat measurement was denoted with a (+) for six of the measurements (samples BGX-02-013A, -029A, -032A, -043A, -044A, and -048A). The (+) denotes that the actual temperature was not available so a substitute nearest available temperature was used. Because there were problems with seven of the eight pairs of repeated temperature measurements, leaving only one valid data pair, no evaluation of the quality control temperature samples could be performed.

3.2.2 Temperature Results. Table 3-7 lists summary statistics for temperature data. The temperature of the SETH munition in the rear of the magazine had the highest average temperature while the SETH munition in the front of the magazine had the lowest average temperature.

The SETH item in the rear of the magazine also had the greatest standard deviation meaning that the rear of the magazine had greater variability in temperature than either the front or middle locations.

Table 3-7. Summary of Temperature Data

Parameter	Rear	Middle	Front	Average of Rear-Middle-Front	Interior of ECM
Number of data points	87	87	87	87	77
Mean (°F)	72.82	66.35	65.45	68.20	69.54
Standard deviation (°F)	2.39	2.11	1.69	1.94	2.74
Normal distribution	Yes	No	Yes	No	No

Notes:

°F = degrees Fahrenheit
ECM = Earth Covered Magazine

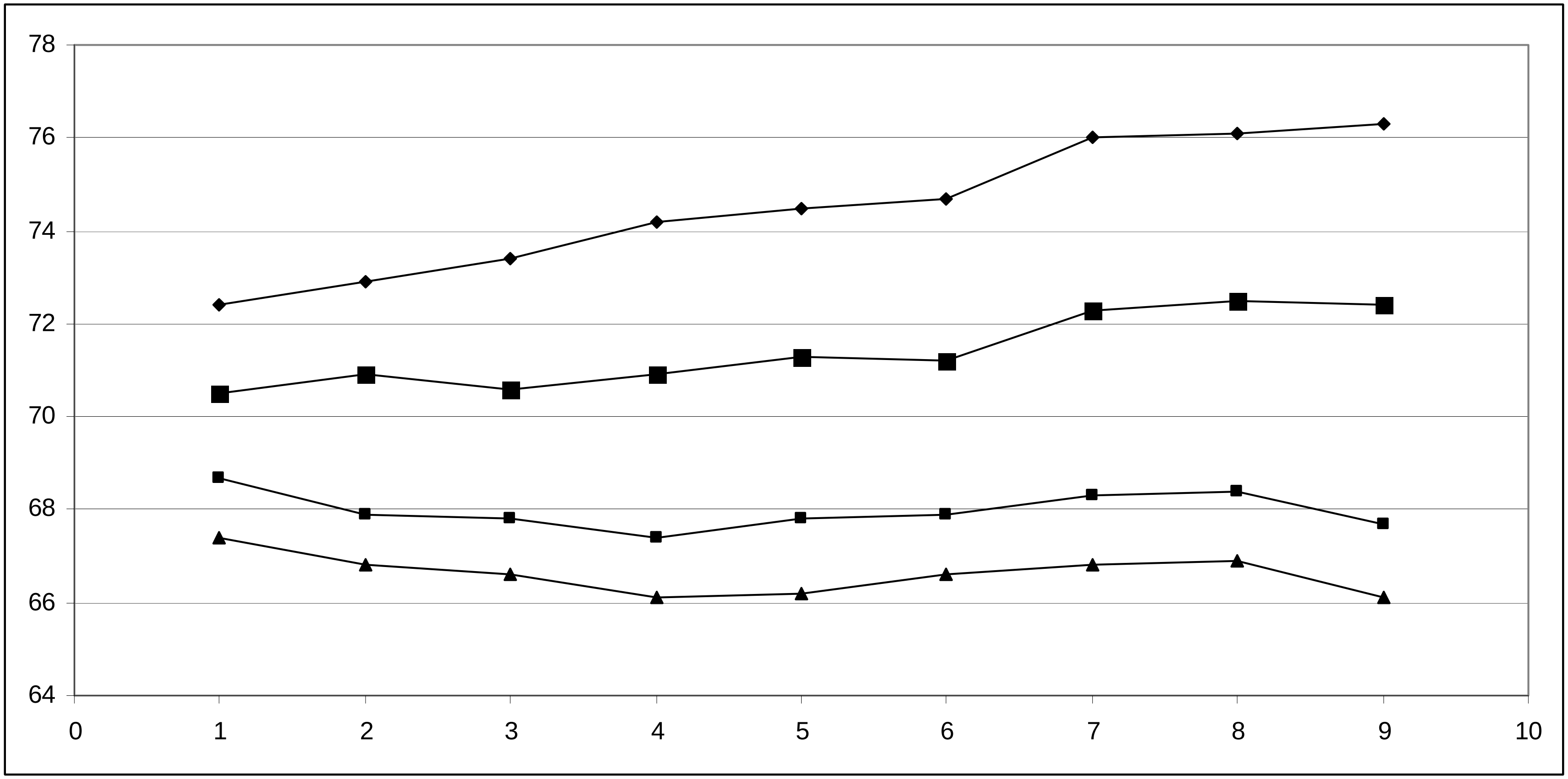
3.2.3 Comparison of Means. The SETH item in the rear of the magazine had the highest average temperature followed by the SETH item in the middle of the magazine, followed by the SETH item in the front of the magazine. To evaluate whether these differences were statistically significant, a Wilcoxson Ranked Sum test was performed for each combination (rear vs. middle, rear vs. front, and middle vs. front). A confidence value of 5 percent was used. Based on these tests, the temperature data for the rear was determine to be significantly greater than either of the other two locations. Likewise, the temperature difference between the middle and front positions was also statistically significant.

Because the data sets for the front and rear positions were normally distributed, a 2-tailed t-test for paired data at $\alpha = 0.05$ was performed for comparison of these two data sets. The results of that comparison also led to the conclusion that there was a significant difference between the two data sets.

The three SETH measures—front, middle, and rear—were averaged to produce an average SETH temperature. This average temperature data set was compared to the interior of the ECM data set. Based on the Wilcoxson Ranked Sum test, the average SETH temperature and the interior of the ECM were significantly different.

Figure 3-6 depicts temperature measurements graphically. The top line represents temperatures recorded on the SETH item in the rear of the magazine. The other three lines are, from top to bottom, the temperature of the air in the ECM, the temperature of the SETH item in the middle of the magazine, and the temperature of the SETH item in the front of the magazine. All temperatures were sorted in ascending order based on the temperature in the rear of the magazine.

3.2.4 Discussion. The draft Noblis *Statistical Sampling Plan for Non-Intrusive Assessment of 155mm Mustard Projectiles Stored at Blue Grass Chemical Activity*, June 2010, reported that temperature fluctuations can influence formation of mustard heel. The report further stated that it was believed that temperature fluctuation would



Notes:

◆ = SETH temperatures from rear of magazine
■ = Air temperatures from interior of ECM
▪ = SETH temperatures from middle of magazine
▲ = SETH temperatures from front of magazine

Figure 3-6. Temperature Data Sorted in Ascending Order of SETH Rear Position be greatest near the door to the magazine and that temperatures would be lower further away from the door.

The two assumptions regarding temperature—that there is more fluctuation in the front of the magazine (near the door) than further inside and that temperature is lower further inside the magazine than near the door—are not supported by the temperature data collected from SETH items. The highest temperature was found furthest from the door. Furthermore, the temperature data from the front of the magazine (nearest the door) had the smallest standard deviation of all three SETH sampling locations.

The average air temperature inside the igloo was 1.34°F higher than the average of the three SETH sampling locations, but 3.28°F lower than the temperature of the warmest SETH sampling location at the rear of the magazine. As would be expected, air temperature measurements displayed a greater standard deviation than any of the SETH sampling locations.

3.3 Observations from Assessment of Previously Overpacked Munitions

X-ray examination was performed on 80 munitions previously identified as “leakers.” Table 3-8 summarizes results of the previously overpacked munitions evaluations.

Table 3-8. Summary of Previously Overpacked Munitions Data

Parameter	Leakers
Number of munitions examined	80
Total fill (sum of liquid and heel)	
Mean	86.7%
Standard deviation	5.4%
Median	87.4%
Maximum	97.6%
Minimum	74.3%

The previously overpacked munitions were X-rayed in an upright orientation to avoid potentially causing more leakage from the munitions being inverted. Measuring liquid and heel volumes with a munition in the upright orientation allowed an accurate measurement of total fill but presented difficulty in differentiating the fill between liquid and heel. Dividing the total fill into liquid and heel was difficult because the interface of the liquid and fill may not be uniform across the diameter of the cavity.

Another complication in measuring liquid and heel levels in previously overpacked munitions is that in some cases, liquid or heel was seen outside of the agent cavity. There was no suitable method of measuring the amount of material outside the agent cavity; therefore, this amount was estimated by visual inspection.

Thirty-five of the 80 previously overpacked munitions had liquid outside of the agent cavity. Two of the previously overpacked munitions had heel identified outside of the agent cavity. Fifteen of the previously overpacked munitions had some type of residue in the fuze well. It has been hypothesized that this residue is excess threading compound applied at the time that the bursters were assembled. Table 3-9 provides a summary of observations made.

In two cases, liquid was identified inside the overpack of a previously overpacked munition. Nine of the overpacked leakers had residue or debris inside the overpack. However, this may not be a significant observation because the personnel performing the assessment were not present at the time the munitions were originally overpacked; therefore, there was no firsthand knowledge as to what materials were placed in the overpack. Consequently, any shadow appearing on the X-ray would likely be interpreted as unknown debris or residue.

3.4 Summary

3.4.1 Percent Heel. The average percent heel was determined to be 54.8 percent with a median of 51.4 percent. Therefore, on average, somewhat more than half of the

Table 3-9. Observations on Previously Overpacked Munitions

Parameter	Observations
Selection	• The 80 previously overpacked munitions were all the leakers available at the time of the project.
Packaging	• 64 of 80 previously overpacked munitions were in PCCs; 1 in double PCCs; 15 in SRCs.
Orientation	• Previously overpacked munitions were X-rayed in upright position.
Liquid outside of agent cavity	• 35 previously overpacked munitions had liquid in the fuze well. • 2 previously overpacked munitions had liquid in the overpack.
Residue outside of agent cavity	• 15 previously overpacked munitions had residue in the fuze well. • 9 of the previously overpacked munitions had residue or debris in the overpack. • 2 previously overpacked munitions had heel just above the bottom rotating band.

Notes:

PCC = propellant charge can
SRC = single round container

fill material in the munitions X-rayed has been converted to or is trapped within a heel. This equates to approximately 2,200 mL of heel.

Evaluation of the heel data from magazine to magazine, from location to location within a magazine, or by lot number did not reveal any statistically significant patterns.

It was not possible to compare initial and repeat heel measurements based on temperature, though it was possible to compare repeat heel measurements to initial heel measurements. The average of 7 initial heel measurements was 74.9 percent while the average of the 7 repeat measurements was 74.3 percent. This difference is not statistically significant.

3.4.2 Temperature. Temperature data were somewhat problematic in that there were a number of measurements that were rejected because of problems with temperature measurements or data recording equipment.

Despite these deficiencies, there was sufficient data to perform temperature comparisons for the front, middle, and back locations within the magazines. The back of the magazine was the warmest location while the front location was the coolest. The differences in temperatures between the three locations were statistically significant.

Munition temperatures were averaged and compared to the air temperature within the magazine. The average of all the munitions temperatures was slightly cooler than the average air temperature of the magazine; the difference was statistically significant.

3.4.3 Previously Overpacked Munitions. Approximately 45 percent of the previously overpacked munitions had liquid outside of the agent cavity, and 2.5 percent had heel outside of the agent cavity.

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