FINAL REPORT

Lightweight and Compostable Packaging For the Military

ESTCP Project WP-201218

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14. ABSTRACT

The project’s goal was to demonstrate and validate environmentally friendly Meal, Ready-to-Eat (MRE) coated corrugated fiberboard ration containers to replace the current solid fiberboard used by the Army. The intent was to provide alternative high performing materials to reduce the amount of waste in the field. Materials and design of the containers were developed with a SERDP project and demonstrated and validated with this ESTCP project. The new containers were fabricated at a corrugator using a polymeric coated paper for water resistance and wet strength. The rations were then assembled at AmeriQual Packaging, one of the ration assemblers, producing pallet loads of MRE rations to test. Control containers of solid fiberboard were also fabricated and assembled at the same time, so they could be used as a comparison to the new container for demonstration/validation testing.

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LIST OF ACRONYMS AND SYMBOLS

ACES	Army Center for Excellence-Subsistence
ACR	Assembly Contract Requirements
AGL	above Ground Level
AF&PA	American Forest & Paper Association
AMET	Advanced Materials Engineering Team
ANOVA	Analysis of Variance
APM	Assistant Program Manager
AR	Army Regulation
ARL	Army Research Laboratory
ASTM	American Society for Testing and Materials
ATEC	Army Test and Evaluation Command
AQL	Acceptable Quality Level
BWEC	Battalion-scale waste-to-energy Conversion
BTU	British Thermal Unit
C	Celsius
C	Corrugated
CB	Cigarette Beatles
CB	Current fiberboard box
CF	Corrugated Fiberboard
CAMP	Center for Advanced Materials and Polymers
CDS	Container Delivery System
CEM	Continuous emission monitor
CFD	Combat Feeding Directorate
CFREP	Combat Feeding Research and Engineering Program
CH_4	Methane
CL	Current fiberboard liner
CM	Centimeter
CO	Caron monoxide
CO_2	Carbon dioxide
CoC	Certificate of Conformance
CORR	Corrugation Direction
CRCST	Consumer Research/Cognitive Science Team
CRT	Combat Rations Team
CRTC	Cold Regions Test Center
DA	Department of Army
DDJC	Defense Distribution Depot San Joaquin, California
DfE	Design for the Environment
DLA	Defense Logistics Agency Troop Support
DoD	Department of Defense
DTC	Development Test Command
DSCP	Defense Supply Center of Philadelphia
EPA	Environmental Protection Agency
ESOH	Environmental, Safety, and Occupational Health
ESTCP	Environmental Security Technology Certification Program
F	Fahrenheit
FBA	Fiberboard Box Association

FGRIP	Fielded Group Ration Improvement Program
FID	Flame ionization detector
FIRIP	Fielded Individual Ration Improvement Program
FT	Foot
FY	Fiscal Year
G	Gram
GC	Gas chromatography
GPS	Global Positioning System
HASP	Health and Safety Plan
HAZMAT	Hazardous Materials
HRGC	High Resolution Gas Chromatography
HRMS	High Resolution Mass Spectrometry
HV	High-Velocity
IARC	International Agency for Research on Cancer
IMM	Indian Meal Moth
IN	Inch
IR	Infrared
ISTA	International Safe Transit Association
JCCoE	Joint Culinary Center of Excellence
JSN	Joint Statement of Need
JSORF	Joint Services Operational Rations Forum
JTP	Joint Test Protocol
K	Thousand
KIAS	Knots Indicated Airspeed
KTM	Kineto Tracking Mounts
LB	Pound
LBF	Pound Force
LBS	Pounds
LOD	Limit of Detection
LOGSA	Logistics Support Activity
LV	Low-Velocity

M	Million
M	Meter
MA	Massachusetts
MBL	Moses Biologic
MCE	Modified combustion efficiency
MET	Meteorological
MIL	Military
MIN	Minute
MLS	Montmorillonite-layered silicates
MM	Millimeter
MRE	Meal, Ready-to-Eat
MSL	Mean Sea Level
N	Newton
ND	Not detected
NDIR	Non-dispersive infrared
No.	Number
NSB	No Spectra-Kote box
NSL	No Spectra-Kote liner
NSRDEC	Natick Soldier Research Development and Engineering Center
NWS	Current fiberboard box - no wet strength
OBTF	Open Burning Testing Facility
OCC	Old Corrugated Containers
OFIG	Operational Forces Interface Group
OSHA	Occupational Safety and Health Administration
OTSG	Office of the Surgeon General
PAHs	Polycyclic aromatic hydrocarbons
PCDDs	Polychlorinated dibenzo-p-dioxin
PCDFs	Polychlorinated dibenzofurans
PCF	photometric calibration factor
PEO	Program Executive Officer
PI	Principal Investigator
POC	Point of Contact
POM	Program Objectives Memorandum
PP	Pollution Prevention
PM	Program Manager
PM	Particulate matter
PM1	Particulate matter of 1 micrometers or less
PM10	Particulate matter of 10 micrometers or less
PM2.5	Particulate matter of 2.5 micrometers or less
PM4	Particulate matter of 4 micrometers or less
PRIME	Plastics Removal In the Marine Environment
PSCC	Packaging, Storage, and Containerization Center
PSD	Power Spectral Density
PUF	Polyurethane foam
RAWIN	Radio Wind
RFB	Red Flour Beetles

RH	Relative Humidity
RMS	Root Mean Square
RPD	Relative percent difference
RS	Ring Slot
RSD	Relative standard deviation
RSC	Regular Slotted Container
S	Solid Fiberboard
SAMS	Surface Atmospheric Measurement System
SB	Corrugated Spectra-Kote polymer fiberboard box
SERDP	Strategic Environment Research, Development Program
SF	Solid Fiberboard
SI	Sustainable Infrastructure
SIL	Systems Integration Laboratory
SL	Corrugated Spectra-Kote polymer fiberboard liner
SON	Statement of Need
SOW	Statement of Work
SPSS	Statistical Package for Social Sciences
SQ FT	Square Feet
STD	Standard
STDV	Standard deviation
SUSP WT	Suspended Weight
SW	Single Wall
SVOC	Semivolatile organic compounds
TAPPI	Technical Association of Pulp and Paper Industry
TECD	Technology Enabled Capability Demonstration
TEF	Toxic equivalency factors
TEQ	Toxic equivalency
TISA	Troop Issue Subsistence Activity
TM	Trade Mark
TR	Technical Report
TRADOC	Training and Doctrine Command
TRW	Total Rigged Weight
TTA	Technology Transition Agreement
UL	Unit Load
UN	United Nations
V	Victory
VETCOM	Veterinary Command
VOC	Volatile organic compound
W	Weather Resistant
WAM	Wax Alternative Medium
WarSTAR	Warfighter Science, Technology and Applied Research
WHO	World Health Organization
WMU	Western Michigan University
WP	Weapon Systems and Platforms
WRAPS	Waste Reduction Afloat Protects the Seas
YPG	Yuma Proving Grounds

XAD-2 Brand name of sorbent polymeric resin (crosslinked polystyrene copolymer)

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DEDICATION

This project and report was dedicated to Mr. Charles Propst, Past President of Spectra-Kote, and Gettysburg PA. Thank you to Charles who was a trusted technical partner in this effort. He fully supported this Army project with not only supplying the coated paper, but he shared his technical knowledge about fiberboard with me. He believed in this Army effort to explore coated corrugated containers. He was always a pleasure to work with. He always had the answers to my questions, before I even asked the questions! I visited Spectra-Kote during the project to tour the facility, discuss the project and update Charles on the work. He was extremely helpful, always believed in me and appreciated the Army efforts to reduce solid waste with this container. Thanks to Charles for being Charles. I truly miss his energy, dedication, personality and expertise. He did an outstanding job at Spectra-Kote and he was extremely proud of his work, his colleagues and his coatings. Each time I spoke with him, I told him to keep his patience and that I was dedicated to transitioning this technology to the warfighter. That was then, but now my feelings and passion to transition this technology was even stronger today because of Charles. I thank him for being a gift during this project and an inspiration to me and my career.

Mr. Charles Propst
1949-2015

EXECUTIVE SUMMARY

The project's goal was to demonstrate and validate environmentally friendly Meal, Ready-to-Eat (MRE) coated corrugated fiberboard ration containers to replace the current solid fiberboard used by the Army. The intent was to provide alternative high performing materials to reduce the amount of waste in the field. Materials and design of the containers were developed with a SERDP project and demonstrated and validated with this ESTCP project. The new containers were fabricated at a corrugator using a polymeric coated paper for water resistance and wet strength. The rations were then assembled at AmeriQual Packaging, one of the ration assemblers, producing pallet loads of MRE rations to test. Control containers of solid fiberboard were also fabricated and assembled at the same time, so they could be used as a comparison to the new container for demonstration/validation testing.

After the assembly, the pallets were stored and stacked 4 high at a constant temperature at Marengo Caves, Indiana to validate the stacking strength as a function of time in comparison to the solid fiberboard. Deflection as a function of time was recorded for a year and both types of containers, with the stack configuration of 4 pallets high, were intact after the one year period.

These pallets and containers were then used for the quantitative and qualitative performance. Quantitative performance objectives included: weight reduction, compression strength, repulpability, recyclability, emissions, waste-to-energy conversion, biodegradability, insect infestation, aerial delivery, and distribution/transportation. The qualitative performance objectives included: solider acceptance, ease of manufacturability, and ease of assembly, which were evaluated using surveys and observations by soldiers and assembly workers handling the new container.

Weight reduction

With this new container, there was an approximate seventeen percent weight reduction in the MRE coated corrugated container in comparison to the solid fiberboard container. A detailed comprehensive study was performed by Tobyhanna LOGSA to determine the weight difference of the ration containers taking into account the weights of all 24 MRE menus. This significant weight reduction allows more cases of MREs to be shipped per truckload, since the shipping trucks currently reach maximum weight, before the maximum cube is reached. As a results, an extra pallet of MREs (48 cases of MREs, 576 meals) can now be loaded on trucks with this new container. This weight savings lowers the overall logistics burden, resupply operations, and fuel usage.

Case and Pallet Performance

A standard practice for performance testing of shipping containers, ASTM D4169, was performed with Tobyhanna LOGSA to examine the performance of cases and pallets under environmental conditions. The stacking load for the pallets was 4 high, and a variety of testing was done to verify its performance in comparison to the solid fiberboard container. The compression testing proved that the compression strength are comparable in the solid and corrugated container.

Demonstration of Recyclability
Western Michigan University's certified laboratory for the Fibre Box Association performed a voluntary standard for repulping and recycling of the corrugated fiberboard and solid fiberboard. The corrugated industry developed the standard for corrugated structures that are developed to improve performance in the presence of water and water vapor. The new coated corrugated fiberboard container was tested, proven and certified recyclable, whereas the current solid fiberboard container was not due to delamination of the paper and its resistance to breakdown for repulping.

Demonstration of Biodegradation
Biodegradation and bio-based studies in compost were performed using standard test methods (ASTM D5338 and ASTM D6866) and specification (ASTM D6400). All components of the coated corrugated structure were tested including the polymeric coating, adhesives and paper. All components were bio-based but the adhesive and coating did not meet the 90% biodegradation within 180 days, which is the specification requirement for D-6400. The materials did show a range of biodegradation from 30-50% biodegradation. The solid fiberboard was tested in the former SERDP studies and did prove to be biodegradable and bio-based despite the wet strength additive. The wet strength additive was not tested separately in any biodegradation or biobased testing.

Testing of Emissions
Waste at forward operating bases is often incinerated or burned on site resulting in potential exposure of military personnel to the emissions. A significant portion of the waste burned consists of MRE ration fiberboard container packaging. Emissions from burning the MRE solid fiberboard and coated corrugated container were characterized in an effort to determine if the combustive disposal of waste at forward operating bases poses an environmental or inhalation threat. The containers were burned with and without coatings and wet strength additives in EPA's Open Burn Test Facility that simulated the burn pit disposal methods in Iraq and Afghanistan. Research into more effective packaging materials has led to the development of polymeric coatings of the fiberboard containers. To assess the influence of these new polymeric coatings on potential combustion emissions, burn studies were conducted by EPA.

Emission testing included measurements of CO_2, CO, $PM_{2.5/10}$, metals, volatile organic compounds (VOCs), PM by size, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated dibenzodioxin/furan (PCDD/PCDF). Analyses determined emission factors, or the mass of a pollutant per mass of original fiberboard packaging. No significant differences in PM_{10}, VOCs, PCDD/PCDF, and PAHs were noted between the polymer-coated and uncoated packaging types for the corrugated fiberboard and between the solid fiberboard with and without the wet strength additive. Comparisons between the packaging types found slight statistical differences between the $PM_{2.5}$ for solid and corrugated fiberboards, with lower values for the coated polymeric material regardless of the presence or absence of the polymeric coating. Emission factors, particularly VOCs, were negatively correlated to modified combustion efficiency. As combustion quality improved, VOCs and, less notably, PCDDs/PCDFs declined. No statistical differences could be observed between same packaging materials with the addition of the wet strength polymeric coating in the corrugated or with the wet strength additive in solid fiberboard.

In the presence of the polymer, PCDD/PCDF emission factors were almost three times higher for the corrugated packaging material than the same material without the polymeric coating. Overall emission factors, however, were consistent with those found for biomass and, in some cases, even lower. In general, little distinction was observed when comparing emission factors from the fiberboard materials. The majority of PM emissions were of particles that were below 1.0 µm in aerodynamic diameter for the fiberboard tests.

Additional tests in which MREs were added to the packaging showed that the MREs were responsible for the majority of the PM emissions. In addition, EPA found in this study that PAH emissions for the packaging alone were much lower than previously observed in EPA's prior studies of military installation waste in an air curtain incinerator. Emission factors determined from these studies can contribute to future military, food, and packaging waste studies to determine potential exposure issues for military personnel at forward operating bases.

Demonstration of Waste-to-Energy

Trials were also done with a waste-to-energy converter with Info-Scitex to assure that the new fiberboard could be processed in the converter. The primary outcome from the waste-to-energy conversion test conducted at Ft. Benning was that both the current solid fiberboard and the new corrugated coated fiberboard for MREs could be processed in the converter. Both materials were used to create a biomass stream that effectively converted to pellets, fueled the gasifier and generated electrical power. The feedstock formulations were controlled with 5 constituents: fiberboard material; water, vegetable oil dried food, plastic. In order to make optimized pellets with high density and a low percentage of fines, particles passed through a pelletizer where the feedstock had to be shredded and homogenized in the shredding process. The coated corrugated fiberboard was more readily homogenized than the fiberboard. The homogenous shred produced from the trial demonstrated that the coated corrugated fiberboard made better pellets than the solid fiberboard with fewer fines, 9% vs 24%, respectively. The efficient pelletization results of the coated corrugated fiberboard revealed that the preferred fiberboard for waste-to-energy conversion operations is the trial corrugated material.

Insect Infestation Testing

There were also some insect infestation studies performed with samples of fiberboard and with the fully packed MRE containers to determine if there was any insect penetration. Fiberboard samples were tested before the full containers were tested and showed minimum penetrations. Then, there were 25 cases of current solid fiberboard packaged MREs and 25 cases of corrugated packaged MREs. All 50 cases were tested for infestation resistance in a climate controlled building. Environmental testing conditions were 80 ± 5^{o}F and $65 \pm 5\%$ RH. Insect species used were the red flour beetle, cigarette beetle and Indian meal moth. Test duration was 12 weeks. Despite more penetrations in the corrugated container than the solid fiberboard container, the MREs were safe as the meal bag that holds all the food did not allow any penetrations.

Demonstration of Air Drop

Air drop trials took place at both low and high altitude at Yuma Air Force Base and Fort Devens, MA. Full inspection of the food products and pouches ensured that both the corrugated and solid containers kept the food safe. There were was a comprehensive data set analyzed with statistical analysis for each food component and its packaging. The prevalent defects in the coated corrugated container were adhesive failures, bottom and/or edge (corner) crush, excessive gap width for the flaps, and puncture. The outcome was that corrugated containers had more physical damage than the solid, but most importantly these containers perform the function of keeping the ration food safe for the warfighter.

Transportation/Distribution Demonstration

The transportation/distribution study took place over a year where pallets of rations were first transported to Alaska, inspected upon arrival, stored for two months and then inspected before departure. Then, the pallets were transported to Washington, Texas and Georgia and underwent the same type of inspections. This study simulated cold, hot, humid and dry conditions as well as all types of transportation which included truck and ship. The containers had some similar outer physical damages that were found in the air drop study especially with the coated corrugated, but the rations were again safe for consumption.

Manufacturing and Assembly Demonstration

The coated corrugated containers are easily manufactured at any corrugator that will work with coated paper. The company that worked with NSRDEC on the project has done numerous trials for the Army using the coated paper and they have other customers who also use a similar type of coating. The design of the container was similar to the existing solid fiber container to minimize problems during assembly. The assembler adjusted and modified their assembly line so these containers would work with the existing equipment. The glue for sealing the container was different than the existing glue, so the glue nozzles would have to be changed if the Army converted to these new containers. Each of the three assemblers packed out the different ration menus in the corrugated container to ensure that the container did not change the rate of assembly. Each assembler answered a survey and questions pertaining to the new container. There would be some changes on the labor intensive assembly lines to accommodate the corrugated container.

Warfighter Acceptability

The warfighter's acceptability was the most important feedback to consider. The warfighters had the opportunity to handle and open the new and current container at the same time. The warfighters answered a survey and also got to talk to the Principal Investigator and team engineer about the container. The warfighters mostly liked the container because it was lighter, but found it harder to open especially since the assemblers had applied extra glue to seal the containers. The warfighters also rough handled the containers to see how sturdy they were on the field. The warfighters all had difference of opinions on the containers depending on their experience in the Army. There was no significant negative feedback on the container.

Transition Process

The container was chosen for the Science and Technology Objective – D for 2016 Selected Technology Assessment where there was visibility within the Army to see the technology and view these ESTCP results. The containers have been shown to other Army installations for packaging other Army items besides ration packaging. The cost of the container was comparable to the solid fiberboard container depending on the fluctuation of cost of paper. This new coated corrugated fiberboard container for the Army has met performance needed for the MRE rations.

In November, 2017, the Principal Investigator attended the SERDP/ESTCP symposium and presented the poster on this effort. There was a lot of renewed interest from the services. The PI then asked the Combat Feeding Directorate to present at the upcoming JSORF. In February, 2018 a decision brief was made to the voting members of the Army, Air Force, Marines and Navy. The voting members were asked to vote and give feedback/questions for the containers. There were multiple questions and concerns for the height and footprint of the container to see if it would fit in an aircraft.

During the brief, discussion amongst the JSORF voting members led to several key questions being asked, which required follow-up action by the CFD/NSRDEC prior to obtaining JSORF concurrence on approving transition to the proposed new MRE shipping case. Specifically, the questions raised were concerning case overhang at the pallet level, fit of pallets in the Multi-temperature Refrigerated Container System (MTRCS), and fit of double-stacked pallet loads into C-130s (in support of aerial delivery). CFD's conclusion based on the tests/analyses conducted is that there are no additional load or fit limitations introduced by transitioning from the current solid fiberboard to the new coated corrugated MRE shipping case.

CFD requested that JSORF review an information paper and to support CFD's recommendation to approve transition to the new coated corrugated MRE shipping case. The concurrence and approval from all services, allows CFD to begin transitioning the required technical requirements to Defense Logistics Agency - Troop Support for proposed implementation during the 2019 MRE production year.

All Services have now concurred (August 2018) with converting to the new lightweight, polymeric coated corrugated MRE shipping case. The next step is to start communicating the proposed change with the 3 assemblers. This will be a discussion topic at Research and Develop Agency meeting in fall 2018. The ACR-39 will be edited after CFD obtains feedback from the 3 assemblers and determine a path and timeline for implementation.

Appreciation to Environmental Partners

This was effort that was primarily funded by SERDP/ESTCP with some leverage with internal NSRDEC's projects, however this effort would not have been successfully completed without the support of SERDP, Pollution Prevention (Zero Footprint Camp), and ESTCP. The teams and partners worked diligently on this project and were dedicated

throughout the many phases until completion. This is not an ordinary container, but one that performs its function of keeping the food safe for the warfighter.

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1.0 INTRODUCTION

1.1 BACKGROUND

The environmental problem of solid waste generated by Meal Ready-to-Eat (MRE) rations and its discarded packaging was being addressed in this demonstration/validation program. Field feeding operations during training and combat activities generate large amounts of packaging related waste during in-the-field consumption and over time create an additional logistics burden on support personnel and Warfighters during waste collection and reverse logistics activities, such as backhauling of in-theatre waste. This coupled with the increasing costs of raw materials, packaging conversion, transportations costs and disposal fees has dramatically increased the need to investigate light-weight alternative materials and designs for combat ration packaging applications. In 2011, the Joint Services procured 36 million individual rations or 3 million cases which generated approximately 6.93 million lbs of solid waste, directly attributed to packaging waste from the existing (2.31 lb.) solid fiberboard case. In comparison, the alternative design, which was the focus of this project, only requires 1.8 lbs of fiberboard in its construction and would only generate 5.4 million lbs of packaging related waste, creating a savings of approximately 1.53 million lbs of waste per year.

Secondary packaging serves a vital role in protecting military rations against destructive hazards encountered during transport; handling; and storage; and must maintain high levels of performance in any environmental condition. Corrugated fiberboard structures have been investigated by the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) as a viable replacement for unique military grade fiberboard packaging material. The redesign of the combat ration secondary packaging began in 2006 with support and funding from the Strategic Environment Research, Development Program (SERDP) project "Lightweight and Compostable Fiberboard for the Military" (WP-1479) and the Combat Feeding Directorate (CFD), Combat Feeding Research and Engineering Program (CFREP) in an effort to make combat ration packaging lightweight and compostable, while dramatically eliminating post-use waste generated during training and combat activities.[1,2,3] These efforts have developed novel secondary packaging systems that utilize lightweight materials with reduced paper fiber content, that exhibit similar compressive resistance and protection when compared to the existing systems. The new containers also have improved functionality with the incorporation of commercially available water resistant coatings that are both repulpable and recyclable, adding a new avenue of recovery for military logistics. Integration of new packaging materials and designs will create substantial benefits impacting life cycle sustainment demands; reduce material consumption; reduce energy and transportation costs; decrease the environmental footprint, reduce the amount of waste to burn pits, and provide significant improvements in waste management activities. This was accomplished by lowering packaging related waste and developing a recyclable container that was designed for improved end-of-life recovery.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this effort was to demonstrate and validate coated corrugated fiberboard secondary packaging for the military that was developed during the Strategic Environmental Research and Development Program (SERDP) project, *"Sustainable Fiberboard Packaging for the Military"*, as well as industry based developments in the area of corrugated fiberboard for shipping containers that have matured into commercially available products. Coated fiberboard packaging for the MRE individual ration will be demonstrated at the commercial production scale and evaluated to reduce Department of Defense (DOD) specific waste problems by developing lighter-weight and recyclable military ration packaging which also meet combat ration operational requirements. The goal was to transition mature technologies to material converters and to assess commercial scale manufacturability, validate assembly operations and confirm durability of fiberboard packaging structures within the military logistics network to include survivability during long term storage and transport operations.

CFD provides the DoD with a Joint Service program responsible for Research, Development, Integration, Testing, and Engineering for Combat Rations, Food Service Equipment Technology, and Combat Feeding Systems. In addition, CFD provides technical support to the Joint Services, Defense Logistics Agency (DLA) Troop Support, ration assemblers and materials providers. The proposed packaging systems were evaluated under CFREP and were monitored for technical progress. CFREP, having total life cycle responsibility for all combat rations and associated packaging systems, has two funded 6.4 system development and evaluation continuous product improvement programs in the Program Objectives Memorandum (POM), namely the Fielded Individual Ration Improvement Program (FIRIP) and the Fielded Group Ration Improvement Program (FGRIP).

1.3 REGULATORY DRIVERS

The demonstration, validation and full integration of ration packaging technologies are relevant to DoD continued efforts to transfer advanced environmental technologies to the Warfighter and directly supports current U.S. Army Technology Enabled Capability Demonstration (TECD) initiatives to include: TECD 2.a Overburden – Physical Burden, 4.a Sustainability/Logistics – Basing, and 4.b Sustainability/Logistics – Transport, Distribute & Dispose, through the reduction of packaging related waste. This proposal also addresses Current Force Capability Gap Area #4 Logistics and Medical, and also supports the Future Soldier Initiative vision that requires the Soldier possess agility, adaptability, mobility, and the ability to act efficiently and effectively to simultaneously perform operational activities. The project also supports efforts toward better environmental management and addresses Draft FY07 Army Environmental Requirements and Technology Assessment documents PP-5-06-01 "Zero Footprint Base Camps" which include elements of the previous Requirement, 3.5.c, "Solid Waste Reduction", a top-ranked pollution prevention requirement.

The effort also supports internal NSRDEC, CFD initiatives to provide and develop advanced technologies, innovations, and concepts for novel systems, capabilities and/or methodologies to enhance distribution-based combat ration sustainment operations that deliver the right rations, to the right place, at the right time, over extended distances in support of global deployments. The project also supports improvements in logistics and sustainment delivery concepts that optimize operational efficiency, optimize cost effectiveness, ensure Warfighter acceptability, and achieve strategic responsiveness for highly mobile, rapidly deployed forces involved in extended operations requiring Class 1 resupply.

This environmental effort addresses the harmful chemicals in the current solid fiberboard formulation.

Table 1 indicates the harmful water resistant chemicals which are currently used in the construction of the MRE solid fiberboard container. The exact formulation of the wet strength additive and the container was unique to the manufacturer. Although the chemical makeup of these additives are unknown, it was known that the material was deemed non-repulpable by industry standards. The new prototype containers being demonstrated have coatings that are compatible with reprocessing/recycling facilities for paperboard products and are deemed non-hazardous.

Table 1. Target Hazardous Material (HazMat) Summary

Target HazMat	Current Process	Applications	Current Specifications	Affected Programs	Candidate Parts and Substrates
Wet Strength Additive	Solid Fiberboard Manufacturing Process	Military Packaging for Combat Rations	ACR-M-032, Section D-3 Packing with reference to ASTM D4727M	DLA Troop Support – Subsistence Supply Chain	MRE Solid Fiberboard Packaging

Numerous Executive Orders for "Greening the Government" have been issued to help conserve the environment and its natural resources through waste prevention, energy management, recycling and acquisition of bio-based products. Government agencies such as the EPA, United States Forestry Service and DoD operate extensive research programs that are focused on preserving natural resources through scientific research and effective resource management.

One such government program was SERDP, DoD's environmental science and technology program that confronts environmental issues for the Army, Navy, Air Force, and Marines. SERDP programs develop environmental responsible technologies to reduce cost and environment risk while enhancing overall safety, health and military readiness. Technologies that successfully pass through the SERDP program are often transferred to the Environmental Security Technology Certification Program (ESTCP) which integrates innovative, cost-effective environmental technologies through demonstration and validation. Lab-proven technologies are evaluated at operational sites to ensure compliance with DoD environmental requirements which are subject to extensive trials that evaluate performance, cost and market potential. Environmental technologies that successfully complete the ESTCP process are then transferred across DoD installations for operational employment. SERDP and ESTCP programs confirm that performance, cost and sustainability can work together to create effective environmental technologies. Other notable government programs that support sustainability include the Design for the Environment (DfE) Program, Navy - Waste Reduction Afloat Protects the Seas (WRAPS) and Plastics Removal In the Marine Environment (PRIME) programs, and the Army's Zero Footprint Camp initiative which find innovative methods to minimize pollution.

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The objective of this effort was to demonstrate and validate novel packaging systems which have been developed during earlier research efforts, primarily through the SERDP project, "Lightweight and Compostable Packaging for the Military (SI-1479)[3] as well as industry based developments in the area of secondary packaging that have matured into commercially available packaging structures utilizing wax alternative coatings. These efforts have resulted in the development of a new generation of high performance materials for secondary packaging by incorporating repulpable coatings into commodity fiberboard sheet stock used in a variety of packaging applications. Repulpable and recyclable packaging structures was demonstrated and evaluated to reduce DoD specific waste problems by developing recyclable and lighter-weight packaging which also meet combat ration operational requirements. The goal was to transition mature technology to material converters and demonstrate manufacturability and durability of fiberboard packaging structures within military specific distribution networks, necessary to meet Warfighter sustainment needs.

Figure 1. MRE containers, current solid fiberboard (on left) and prototype corrugated container (on right).

Corrugated fiberboard structures have been developed by CFD in an effort to replace military grade secondary packaging for the MRE with innovative packaging alternatives that are more sustainable and minimize the environmental footprint of ration packaging. The new systems utilize effective designs that accurately accommodate the packaged ration components which minimize overall material usage, creating a more material-efficient delivery system. The prototype containers have also been developed to sustain current performance levels in terms of compression strength and have been tested in standard and adverse weather climates with the use of wet strength coatings to sustain stacking performance in the most challenging environments.

Extensive research by CFD and their team of partners has resulted in innovative corrugated containers designed for MRE ration items and have overcome several design challenges during its development to include coating formulations, board manufacturing trials and container design optimization. Additionally, demonstration of these prototype containers has shown that they can meet stringent military requirements while also providing a clear sustainable advantage; achieving a 10 to 25% reduction in weight over the existing ration packaging. The weight reduction contributed to a potential large-scale savings of 870,000 to 3,400,000 lbs of fiberboard annually, and significantly reduce raw material costs. The optimized container design was created for reductions in procurement, shipping and disposal costs associated with the reduction in material usage and would result in lower life cycle and sustainment costs for combat ration systems.

2.1.1 MRE SOLID FIBERBOARD CONTAINER

The construction of the current solid fiberboard material consisted of three layers of paperboard laminated together with an adhesive applied over the entire area of contact between the sheets as shown in Figure 2. The SF material consisted of two outer facings of 90 lb wet strength linerboard and an inner ply of 69 lb linerboard. The combined material forms a rigid board, and boxes fabricated from solid fiberboard show high resistance to puncture but offer little cushioning to their contents. They do, however, offer greater resistance to rough handling and wear, and are better adapted for use in shipping heavier and less fragile items than those shipped in corrugated fiberboard boxes.

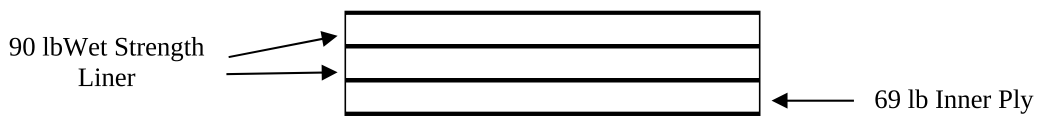


Figure 2. Solid fiberboard structure consisting of two 90 lb wet strength liners and an inner ply of 69 lb

The container was manufactured from rotary cutting die equipment and formed into an industry standard regular slotted container (RSC), additionally a corrugated insert, highlighted in Figure 3 was used for added compression support and product protection. The fiberboard box was constructed according to RSC-L, of ASTM D5118/D5118M, Standard Practice for Fabrication of Fiberboard Shipping Boxes, and grade V2s of ASTM D4727/D4727M Standard Specification for Corrugated and Solid Fiberboard Sheet Stock (Container Grade) and Cut Shapes.[4] The box liner fits inside the full width of the container and was fabricated from grade W5c fiberboard in accordance with ASTM D5118/D5118M. The terminal ends of the liner overlap at a minimum of two inches to ensure full enclosure of the rations and to provide a full gluing surface for closure of the major and minor flaps. The inside dimensions of the MRE container are 16.6875 inches in length, 9.125 inches in width and 10.25 inches in the depth. The full area of the container was 7.33 square feet (sq. ft.) and the full area of the liner was 3.33 sq. ft. The overall weight of the container with the corrugated liner was approximately 2.31 lbs of fiberboard material. Assembled rations use hot melt adhesive to secure the bottom and top flaps and addition strapping was used to further enclose/secure the container once it has been packed with the twelve individual rations.

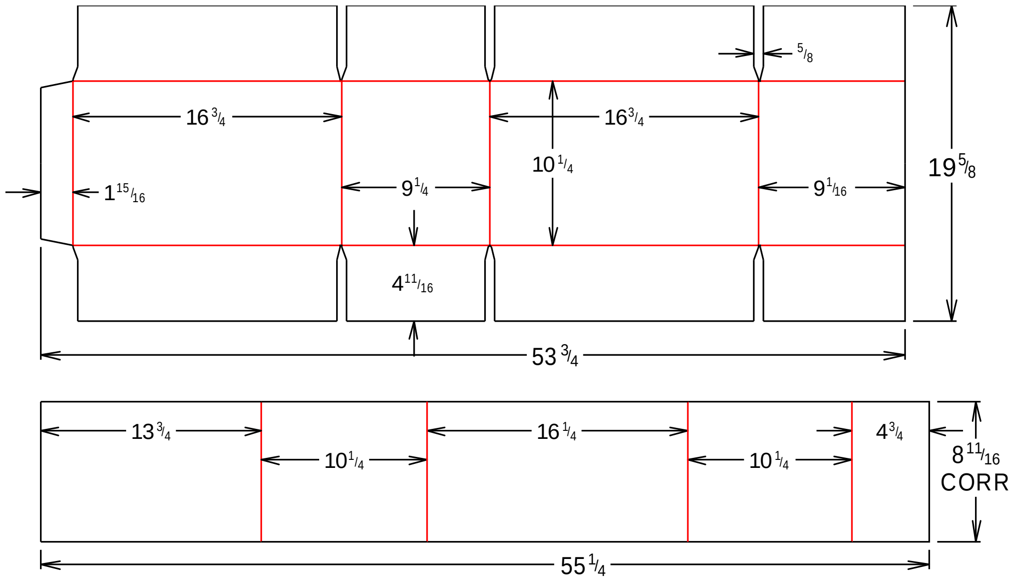


Figure 3. MRE solid fiberboard container (existing) and corrugated insert (bottom)

2.1.2 MRE CORRUGATED CONTAINER (PROTOTYPE*)*

Corrugated fiberboard was fabricated from flat sheets of paperboard (called liners) glued to the fluted linerboard or medium, as shown in Figure 4. Strength requirements are obtained by varying caliper, number, and quality of the component facings and the corrugated medium. Corrugated fiberboard has low resistance to puncture but affords a high degree of resilience and cushioning. Single-wall (SW, also called double-faced), corrugated fiberboard consists of two outer paperboard facings laminated to a fluted medium between the two liners (Figure 4). It was this combination of flat and corrugated liners that gives corrugated fiberboard its qualities of strength and resilience. Corrugated fiberboard was constructed with different kinds and arrangements of mediums, often referred to as “flutes”. The prototype container was made with "C" flute material, with 42 plus or minus three flutes per linear foot. The corrugated liner was constructed from "B" flute material, with 50 plus or minus three flutes per linear foot.

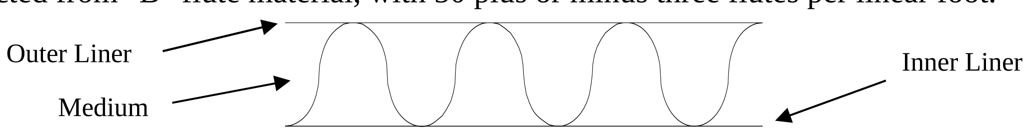


Figure 4. Combined board structure for corrugated fiberboard

The prototype MRE design shown in Figure 5 was constructed into an industry standard regular slotted container (RSC) with internal dimensions of 17 x 10.5 x 8.875 inch. The RSC design also uses a corrugated insert within the container to provide additional support under load and to improve puncture resistance along the side panels of the container. The full area of the container was 7.92 sq. ft. and the full area of the liner was 3.31 sq. ft. The overall weight of the container with the corrugated liner was approximately 1.90 lbs of fiberboard material. As compared to the weight of the existing container, the prototype container was approximately 0.41 lbs lighter in material weight and represents an 18% reduction in packaging material.

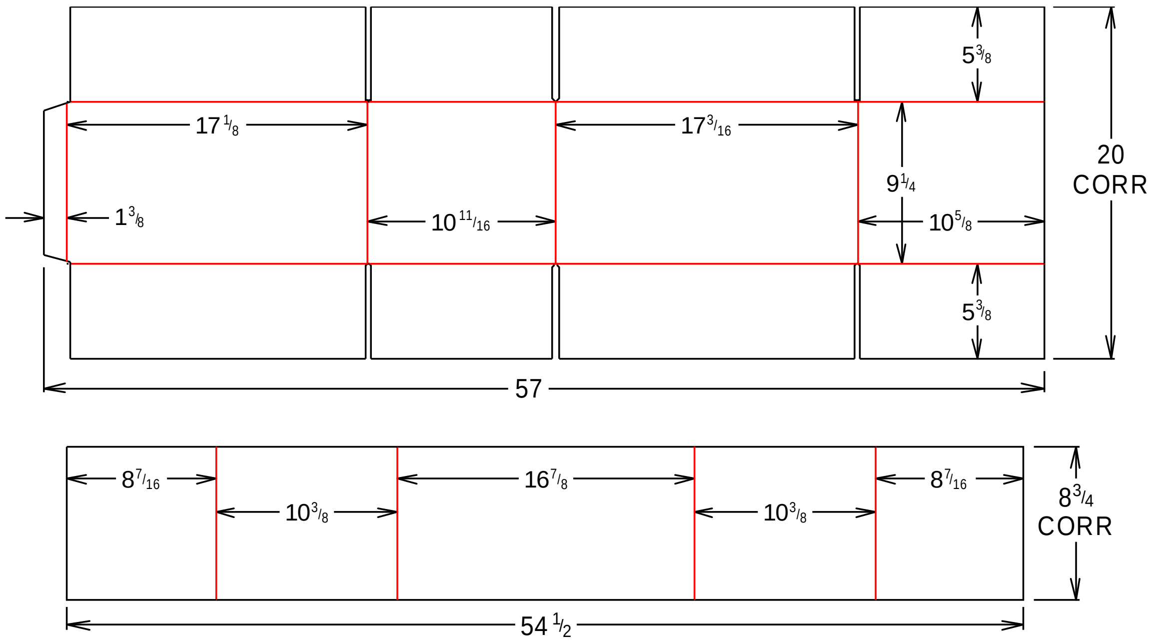


Figure 5. Corrugated fiberboard container formed into a regular slotted container with an internal liner (bottom) for added protection and stacking strength

2.2 TECHNOLOGY DEVELOPMENT

Secondary packaging serves a vital role in protecting military rations with over 40 million rations or 3.3 million cases being consumed each year by the military. These containers currently made with solid fiberboard material are required to maintain high levels of performance during transport in any environmental condition and must survive rough handling events, such as aerial delivery, cross country shipments and endure long-term storage in harsh weather environments. In addition to meeting these strict military requirements, new technologies that produce environmentally friendly, lightweight and compostable fiberboard are needed throughout the Armed Services. These technologies help reduce packaging waste in the field, ease logistic operations and diminish end-of-life disposal costs.

Fiberboard structures which are targeted for the MRE shipping container have shown significant improvements in strength properties (top to bottom compression), as well as mechanical properties such as flexural rigidity. Past research efforts conducted by NSRDEC and industrial partners have resulted in the successful development and technology demonstration of fiberboard container prototypes for the MRE that was comparable to the current packaging. The improved properties of fiberboard packaging enable the replacement of the existing MRE shipping container with packaging that demonstrates weight reduction opportunities while still providing adequate protection functionality.

The improved properties achieved through optimization of the structure and repulpable coatings allow for the replacement of the solid fiberboard structure, and has the potential to reduce the packaging waste by up to 25%, while also providing a recyclable package and minimizing existing performance issues such as container failure and product damage. This proposed effort conducted large-scale manufacturing and operational testing and evaluation of MRE rations which utilize secondary packaging technology. The schematic shown in Figure 6 highlights the coated corrugated fiberboard manufacturing process, using environmentally friendly coatings. The manufacturing process would start with large rolls of coated liners. These two liners would then be glued to a corrugated medium using multiple gluing stations along with heat and pressure. The final product was corrugated medium sandwiched between two liners coated with moisture resistant coatings. By using these coatings in the construction of the new container, it helped improve moisture resistance and mechanical properties of the combined board.

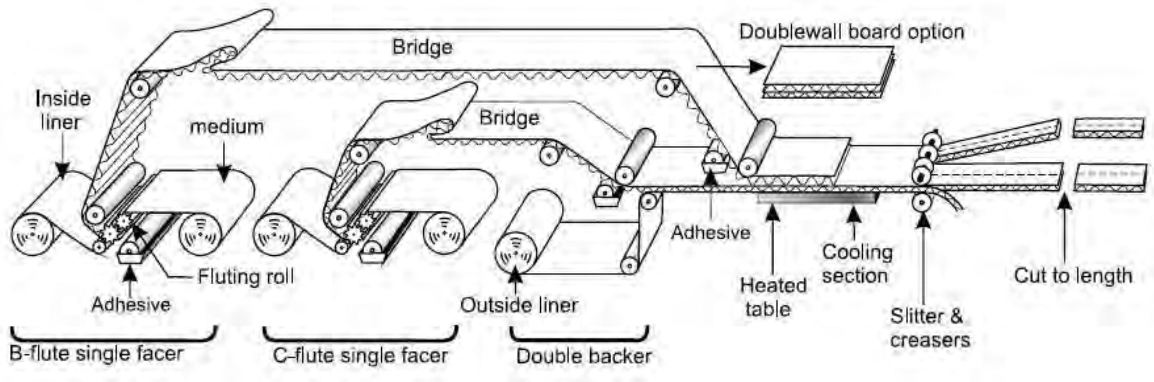


Figure 6. Corrugating machine highlighting the operating stations used during construction of combined board

The NSRDEC has effectively fostered an integrated research team that includes material suppliers/converters in fiberboard, independent testing laboratories, coating suppliers, government research agencies and academia working collectively to develop advanced packaging systems for military rations. This effort has created novel secondary packaging systems that have reduced fiber/material content, which utilize a lightweight coated fiberboard material that exhibit comparable compression resistance to existing solid fiberboard systems. The new containers also have improved functionality by incorporating water resistant coatings that help maintain compression strength in adverse environments. These systems utilize fiberboard coatings that are both repulpable and recyclable, which may provide additional avenues of recovery for military logistics. They also show commercial promise as feasible replacements to wax impregnated fiberboard, opening up new opportunities for the commercial sector to expand both recovery and recycling efforts of corrugated containers.

Several design structures and coating formulations have been developed to meet military requirements and have been subjected to burst strength testing, rough handling, aerial delivery and compression analysis after exposure to standard/adverse conditions. The efforts of this research show promising results with reductions in fiber content, overall weight, and material cost when compared to the existing ration systems. Based on annual requirements, the material reduction in fiberboard would dramatically reduce transportation and disposal expenses which are key elements in overall lifecycle sustainment costs of military rations. These new systems helps expand the production base for military ration containers throughout the Armed Services and also increase the availability of repulpable coatings in the commercial sector. This effort investigated the performance of corrugated containers under adverse environmental conditions, in accordance with unique military requirements and examine new commercial applications for these secondary packaging systems. Figure 7 demonstrates the time line for the numerous projects encompassing fiberboard for military ration applications.

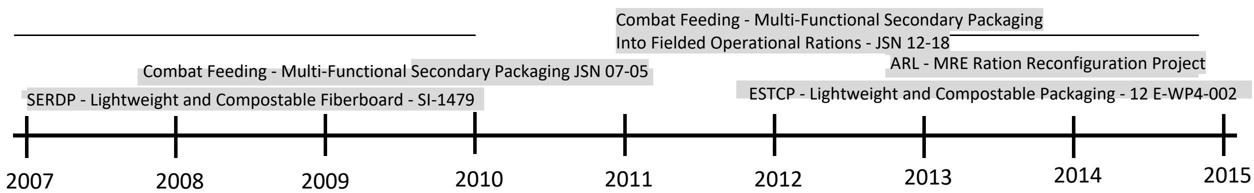


Figure 7. Research and development outline for coated corrugated containers

In 2005, the SERDP SI-1479 project was funded in response to a statement of need (SON) to reduce the packaging waste associated with the consumption and use of combat rations. The SERDP project has transitioned to the "Multifunctional Secondary Packaging" research project funded by the DoD CFREP for FY07-FY10 at $640K for a three year period. A patent disclosure for the fiberboard structures and technology was submitted in 2010 with Interstate Containers.

The coatings for this project utilized applied barrier technology for the container industry and have been formulated for a wide range of performance options.   The barrier coatings have been tested by independent labs and they are certified by the Fibre Box Association (FBA) for repulpability and recyclability. Additionally, in the Lightweight and Compostable Fiberboard for Military Rations project, (SERDP SI-1479) the coated containers were found to be compostable and biodegradable. During compression studies at standard and wet conditions, the corrugated prototype containers have shown similar and even higher compression values over the current ration containers. Rain chamber testing at high intensity for 8 hours have also demonstrated that the water resistant coatings are capable of repelling water and recovering compression capability after exposure to wet environments. Cold weather studies have also demonstrated that the containers / coatings can repel high moisture conditions in cold weather conditions and still retain overall packaging containment and integrity.

Air drop initial trials have also been performed at low and high altitudes and the packaging inspected for defects. Data was analyzed in comparison to the current fiberboard for not only the defects but the location and type of defect. Analysis of Variance (ANOVA) has been applied to the different prototypes with consideration to the design, type of insert, effect of moisture conditions, paper weight and type of coating. The optimized structure has been determined for this project to utilize a paper weight of 69 lbs for the liner and 30 lbs for the medium constructed into RSC with a full insert around the perimeter. This container fits into the current assembly process for combat rations' unit load requirements.

This project leveraged the scientific and technical capabilities of industry, academia, and NSRDEC, through leveraging with past and current projects, including: "Multifunctional Secondary Packaging" (CFREP); "Reduction of Solid Waste Associated with Military Rations" (SERDP); and "Nanocomposites for the Solid Waste Reduction of Military Food Packaging"

(ESTCP). Research efforts also included a congressional plus up with Green Bay Packaging, Wisconsin to investigate alternative fiberboard structures for the military.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The coated corrugated containers are expected to meet the operational and performance requirements of combat ration shelf life and ultimately replace the existing combat ration secondary packaging systems. The advantage of corrugated containers was that there was a wide variety of flutes, medium, liner and paper grades that can be changed in a structure to optimize the performance of the container, yet not influence production manufacturing. This optimization and choice of fiberboard materials were done in the previous Strategic Environmental Research and Development Program. Through incorporation of the environmental coating and the transition to a corrugated MRE container, it was estimated that the amount of solid waste generated can be substantially lessened through the reduction of the amount of paper fiber within the new container. In addition, the fiberboard packaging structures are entirely repulpable and recyclable, providing enhanced end-of-life disposal capabilities that serve to minimize negative environmental impacts of military rations. The optimized structure provides the needed protection during transport, storage and operational use; decrease overall packaging waste; and enhance recyclability making it simpler for military personnel to dispose of packaging waste. Further, it also improves overall sustainability by removing harmful chemicals from secondary packaging structures. A list of attributes in Table 2 highlights the comparative advantages and disadvantages of the existing solid fiberboard containers and the new prototype containers to include elements of cost, military performance, and environmental issues.

Table 2. Comparative Advantages and Disadvantages of Packaging Materials

Functionality	MRE SF	Corrugated
Material Consumption	High	Low
Material Cost	High	Moderate
Production Base / Manufacturability	Low	High
Durability	High	Moderate
Repulpability / Recyclability	Low	High
Weather Resistance	Moderate	High
Compression Strength	High	High
Environmental Impact	High	Moderate

Material Consumption **-** The prototype corrugated containers are approximately 10-25% lighter than existing MRE containers and offer fewer secondary packaging components which reduces material, shipping and disposal costs. The overall weight of the existing container with the corrugated liner was approximately 2.31 lbs of fiberboard material. The overall weight of the prototype container with the corrugated liner was approximately 1.90 lbs of fiberboard material. As compared to the existing container, the prototype container was approximately 0.41 hrs lighter in material weight and represents an 18% reduction in packaging material. In 2011, the DoD Joint Services procured 36 million individual rations or 3 million cases which generated approximately 6.9 million lbs of solid waste, directly attributed to packaging waste from the existing (2.31 lb.) solid fiberboard case. In comparison, the new container would only generate approximately 5.4 million lbs of packaging related waste, creating a savings of approximately 1.5 million lbs of waste per year. Additionally, elimination of excessive fiber content reduces overall packaging weight and create a smaller logistical and environmental footprint for DoD. Commercial packaging as described in this project shall be used when it was cost effective and withstands anticipated logistics conditions

Material Cost – The raw material cost associated with procurement of packaging supplies for combat rations represents a significant investment for DLA Troop Support and DoD. The item unit cost per container was estimated to be lower than the existing solid fiberboard container. Due to the higher availability of materials and an elevated level of competition between suppliers the market for packaging supplies would be more competitive with the use of commercial materials. The final design selection was evaluated for overall cost and include evaluation of design, container size, fiberboard structure and resulting blank size. The estimated packaging costs are based on current economic factors, procurement negotiations, and existing market prices.

Production Base / Manufacturability - Introduction of corrugated fiberboard and alternative coatings into military ration systems creates new opportunities for packaging suppliers and create a larger, more available production base capable of producing MRE containers. The existing production base consists of one primary supplier, International Paper, which currently manufactures solid fiberboard material at the Lancaster, Pennsylvania manufacturing facility. International Paper was the sole provider of solid fiberboard material, supplying ration assemblers: AmeriQual Packaging, Wornick Foods, and Sopakco. The introduction of commercial grade material expanding availability of suppliers and allow the ration assemblers to source packaging materials closer to their assembly operations/facilities. Corrugated manufacturers are capable of producing coated materials through standard equipment involved in paper coating, combined board manufacture, and conversion of board into finished containers to include gluing, printing and folding operations.

Durability – Secondary packaging serves a vital role in protecting military rations against destructive events encountered during global distribution and must maintain high levels of performance in the most severe shipment, handling, and storage conditions. Ration packaging must be capable of protecting material from the effects of direct exposure to extremes of climate, terrain, and operational and transportation environments to include mobilization, strategic and theater deployment, open storage, and deck loading. All packaging materials validated in this project provided the required packaging protection at the lowest overall cost and demonstrate high levels of compatibility with commercial and/or DOD transportation systems to include air, land and sea transport modes. Newly developed packaging concepts are tested to assure survival in the military distribution environment including transportation and storage. Operational requirements for the items are considered when developing packaging designs and obligatory test requirements. These include storage and transportation requirements, such as: must survive storage for up to three years in all climatic regions and; transport by any mode, i.e., rail, ship, air and tactical vehicle. Two key material assessments -- puncture resistance and burst strength -- utilized to evaluate relevant material strength and durability. Based on previous testing, the exacting solid fiberboard material has a higher burst strength that the corrugated fiberboard, in part from the solid board structure and from the heavier liner weights as described in the materials section. Additionally, fully assembled containers were evaluated in relevant environment to determine overall packaging / system durability and were validated through packaging inspection assessments.

Repulpability / Recyclability **-** Elimination of non-pulpable additives allow corrugated fiberboard to be repulpable and recyclable. Military rations converted from a source of waste to a source of reusable material that can be reclaimed as a viable supply of fiber material. Earlier material assessments following FBA protocol, "Voluntary Standard for Repulping and Recycling Corrugated Fiberboard Treated to Improve Its Performance in the Presence of Water and Water Vapor" have shown the existing solid fiberboard material was deemed non-repulpable with an acceptable fiber yield of below 80%. Material used to construct the prototype containers was deemed repulpable through these industry standards.

Weather Resistance - Packaging material for the MRE must adequately protect rations from environmental conditions and the elements by the means of proper storage facilities, preservation, packing or a combination of any or all of these. The type and length of storage anticipated should be one of the major factors in determining the degree of protection to be applied to materiel. Depending on the geographical location, materiel must still be packed for protection against water vapor and possible condensation due to high humidity and extreme changes in temperature. Ration packaging must be compatible with all types of storage facilities to include: general purpose warehouses (heated / unheated), controlled humidity, refrigerated, nontraditional structures and open storage areas with finished / unfinished surfaces. Both the existing MRE solid fiberboard container and the prototype corrugated container incorporate wet strength coatings into their structure and both have a high degree of weather resistance over similar uncoated containers. However, when exposed to wet environments over extended periods of time, the containers may be significantly weakened due to their hygroscopic materials used in the manufacture of the combined board. In extreme wet conditions, the corrugated structures are more susceptible to delamination between the fluted medium and liners, which may result in a loss in compression performance, loss of product containment and may even result in damaged product due to container compressive failure.

Compression Strength – Compression strength of finished containers that are fully assembled are evaluated for performance and was deemed to be the most critical performance measure of the secondary packaging systems. Previous testing and evaluation of individual containers have shown that the MRE prototype containers exhibit similar compression values at standard conditions and superior wet strength performance following exposure to adverse environments (high humidity and rain exposure). In standard laboratory conditions, the existing fiberboard container has compression strength values of approximately 2150 pound-force at the container failure point and the prototype container demonstrated a compression strength average of 2250 pound-force, showing a 5% gain in ultimate compression strength.

Environmental Impact - Environmental pollution prevention measures have been incorporated into the packaging prototype designs and specifications to eliminate excess material and remove harmful wet strength additives found in the existing solid fiberboard material. Previous development efforts have created secondary packaging systems that have reduced fiber content and utilize lightweight corrugated fiberboard instead of military grade solid fiberboard. The lightweight MRE design shows significant annual savings in material with a 1.5M pound average reduction in packaging consumption. The new containers also have improved functionality by incorporating water resistant coatings that are both repulpable and recyclable adding a new avenue of recovery for military logistics, as well as for the commercial market. Efforts to reduce the environmental footprint of combat rations impacting environmental concerns inherent to manufacturing activities, material handling and transport, storage and disposal making the new design a preferred alternative that enhances the environmental sustainability of ration packaging.

Limitations of this technology are that the corrugated structure will never achieve the burst strength of the current solid fiberboard container. This has been previously evaluated and compared to the current MRE containers. The Advanced Materials Engineering Team has created an extensive test plan to reduce the technical risk associated with the integration of these materials into MRE packaging. Testing and evaluation as presented in this demonstration plan was being directed on all levels of packaging with full material testing of the raw materials, simulated laboratory testing of the individual containers, third party testing of the unitized loads and long term storage demonstrations of first article packaging systems. This multi-level evaluation helps ensure material maturity and effectiveness and ensure that it meets current performance criteria for compression strength and durability. Burst strength was in the military specification and therefore the specification would need to be changed to accommodate compression strength values versus burst strength. Compression strength was the performance criteria that should be evaluated for these containers as it can be done at the case level and unit load level.

Results from this demonstration testing and material validation were provided to the Combat Combat Feeding Directorate and should be allowed to be presented to the Joint Services Operational Rations Forum (JSORF). NSRDEC plans to work with two teams in the Combat Feeding Directorate to request modifications to the military specification. The two teams are: 1) Combat Rations Engineering Support Team (CREST) who work directly with Defense Logistics Agency Troop Command, the procuring agency and 2) the Food Engineering Service Team (FEST) of the, who owns, reviews, modifies and edits military specifications. Both teams are familiar with the project and that modifications would be needed for the military specification. Results from the demonstration/validation plan were provided and presented to both teams. JSORF approval will be required to move the containers into the military logistics system and will play a critical role in approving the change to the corrugated technology from the current solid fiberboard containers.

3.0 PERFORMANCE OBJECTIVES

3.1 MRE PERFORMANCE OBJECTIVES

The performance objectives outlined in this section provides the basis for evaluating the performance and costs of the proposed technology; corrugated fiberboard containers for the MRE combat rations. The performance objectives provide a sound basis for evaluating the new packaging design and guide researchers to the successful demonstration and validation of the technology. Both qualitative and quantitative performance objectives, detailed in Table 3 was used throughout the project to assess the material performance of the technology and used as criteria for successful project completion. All performance objectives outlined in this section have clear and measurable goals and show a high degree of relevance to combat ration technologies, key stakeholders and end users.

Packaging metrics applied to military applications can be used as a guideline for packaging design to improve performance, lower procurement and ownership costs and enhance sustainability. Relevant metrics that are well defined form the baseline for packaging requirements and create a development process that maximizes overall performance. These new systems help improve the operational capacity of the Warfighter and minimize the logistical and environmental footprint of ration systems. Metrics with useful military applications may include product-to-package weight ratios; percent recycled content; product density; void space percentage; and transportation effectiveness. Types of metrics examined in this study include packaging performance within the distribution system, costs within the value chain and packaging sustainability. The packaging performance metrics focus on distribution packaging effectiveness. The costs metrics focuses on economic/environmental impacts within the supply chain. The packaging sustainability metrics focuses on strategies that improve packaging sustainability.

Table 3: Sustainable Fiberboard Performance Objectives

Performance Objective	Metrics	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Reduce amount of solid waste generated from secondary packaging	Tons/day of solid, non-hazardous ration reduced waste sent to landfill	Disposal data for solid waste	Greater than 20% overall weight reduction of secondary packaging	FAIL (15% vs 20%)
Maintain compression strength of MRE fiberboard containers	Maintain functioning compression strength (lbf) of containers within representative environments	Compression data from finished containers after environmental testing	Maintain compression strength to support 4 unit loads (3950 lbs) during long term storage	PASS
Ensure repulpability to meet paper mill operating standards during recycling	Percent fiber-on-fiber yield	Fibre Box voluntary standard for repulpability	No more than 15% fiber reject	PASS
Ensure recyclability to meet recycling mill operations	Percent reject of recycled fiber	Fibre Box voluntary standard for recyclability	No more than 10 percent decrease in fiber strength properties	PASS
Ensure emissions from burning of containers contain no toxic chemicals	Identified emission gases from laboratory burn tests	U.S. EPA emissions protocol	Zero identified toxic emissions as a result of burn testing	PASS
Ensure fiberboard can undergo waste-to-energy trials	Convert fiberboard in waste-to-energy converter and measure BTUs	U.S. EPA emission guidelines	Create pellets from waste-to-energy trail	
Ensure biodegradability and compostability of fiberboard	Percent mineralization of chemical carbon in compost/soil	ASTM D6868 specification on biodegradable paper coatings	Meet the requirements of ASTM D6868 specification	PASS
Maintain resistance to insect infestation	Percentage of insect penetrations per 30 containers	Inspection of containers after insect exposure	Less than 20% penetration failure	PASS
Ensure MRE can withstand aerial delivery	Percentage of failures due to bursting of puncture	Percentage of defects on dropped MREs	Less than 12% failure rate	PASS
Ensure MRE can withstand distribution / transportation study	Percentage of packaging defects	Inspection of MREs after distribution and transport cycle	Less than 10% failure rate	PASS
Qualitative Performance Objectives				
Soldier acceptance of container	Field test questionnaire	Survey evaluation from individual soldiers	Positive feedback that soldiers could use this container	PASS
Ensure manufacturability of corrugated ration container	Observation / inspection of converted material	Manufacturing specifications ASTM D4727 & D5118	Complies with industry standards set by Fibre Board Association	PASS
Ensure ease of packing during assembly process pf the MRE rations	Observations during the assembly and packing processes	Feedback and inspection from the converter on the packaging of MRE rations	End item inspection at co-packers with certificate of conformance and production report	PASS

3.1.1 REDUCTION OF SOLID WASTE

The first objective was to reduce the weight of the military rations and reduce the overall packaging requirements. Studies have shown that solid waste was generated at a rate of about 4 lbs per person per day for Force Provider camps and Army field exercises, most of which originates from foodservice operations. This was relevant to the demonstration as the overall goal of this environment demonstration was to reduce the amount of solid waste for the military. Deployed forces and contingency operations generate tons of solid waste that must be burned or backhauled to disposal sites at great expense. With a weight savings, there was less solid waste. The metric used to assess whether the objective was met was to weigh the containers after being manufactured comparing it to the control MRE container. The data required was the weight of these containers after manufacturing trial runs. The success criterion was a weight reduction of 20% of the original container weight which would equate to a 0.46 lb reduction per fiberboard container. As highlighted in Table 4, the prototype container shows an estimated weight reduction of 18% or a 0.41 lb reduction. The estimated reduction in ancillary packaging was expected to further reduce the packaging requirements providing a total packaging weight reduction of greater than 20%. Calculations, shown in Table 4 below, were carried out to determine the magnitude of waste savings. This was relative to the demonstration as this would be meeting the overall objective of the ESTCP project; some initial calculations have been considered and utilize an average procurement of 43M individual rations or roughly 3.6M MRE cases per year.

Packaging decision-makers also need to consider end-of-life of the packaging selected and how it influences their environmental impacts and cost structures. These considerations can range from transportation of used packaging for re-use; producer responsibility in regulatory framework and the costs and benefits of using materials that are recyclable and reusable, versus materials that are disposed of in landfills.

Table 4. Weight Calculations for the Fiberboard Containers

Sample	Case Weight (lbs)	Case Weight (oz.)	Case Weight (g)	Unit Load (UL) (Lbs)	Truckload (38 Uls) (lbs)	Annual Procurement (3.6M cases) (lbs)
Exwasting MRE Container	2.31	37.0	1047.8	110.88	4,213.44	8,316,000
Prototype MRE Container	1.90	30.4	861.8	91.2	3,465.60	6,840,000
Packaging Reduction	**0.41**	**6.6**	**186**	**19.68**	**747.84**	**1,476,000**

The recycling efforts in this project demonstrate that the corrugated shipping containers can be re-pulped by standard industrial processes and be considered for use as a recyclable product in the paper industry. The current solid fiberboard shipping containers cannot be re-pulped, so this added feature was a benefit of the new corrugated containers. The 20% reduction of solid waste mentioned here was based on the measured weights of the corrugated containers in comparison to the solid fiber shipping container. Demonstration of an effective and acceptable performance using the corrugated shipping container indicates the amount of weight that can be reduced in the container while maintaining acceptable performance. The recycling effort was laid out in Section 3.1.3 of the demonstration plan follows voluntary standards issued by the Fibre Box Association on repulpability, a common standard followed in the packaging industry to determine recyclability.

3.1.2 PERFORMANCE - COMPRESSION STRENGTH OF INDIVIDUAL CONTAINERS

The second objective was to evaluate the compression strength throughout the demonstration and through the accelerated and long term storage study. The relevance to the demonstration was that the compression strength in the packaging can relate to the long term compressive strength and unit load performance. This was crucial to track in order to verify the individual container and unit load performance of the packaging. If the packaging performs in comparison to the controls, but does not keep compressive strength, then this was not a successful demonstration. The criteria are that greater than 90% of the containers maintain the compressive strength required to support unit load stacking as compared to the MRE controls.

As the Lead Service Activity for fiberboard boxes and sheet stock, barriers, bags and sacks, adhesives, the Logistic Support Activity (LOGSA), Packaging Storage and Containerization Center (PSCC), Packaging Applications Test Facility was well equipped to perform testing of “Meal, Ready-to-Eat” (MRE) meal bag packaging and secondary shipping containers. For that reason, they were chosen by NSRDEC to analyze the weight and performance of the packages.

Acceptance Criteria

Packaged product was considered to fail if any of the following occur:

- Permanent buckling or creasing of the box during static compression, split top load vibration, and offset top load vibration tests.
- Glue joint failure in box.
- 20% or greater fall-off in static compression strength before reaching required load.
- Product damage or performance reduction.
- Leakage or contamination of product by consumables and/or packaging.
    - Example: Excessive leakage within or outside of product.
- Package no longer continues to protect product.
    - Example: Packaging degrades so product not in correct position within package
- Damaged containers that compromise the structural integrity of pallet.
- Missing bands, clips, or wraps used to secure shipping box to pallet.
- Any change in package condition that creates a safety hazard.
    - Example: Compression damage that creates an unstable pallet load or material de-lamination

Aside from these qualitative measurements, a quantitative measurement that was critical to compression performance was static compression strength which was graded as a pass/fail based on the 20% drop in strength before reaching the required load value. Greater than 90% of the test samples must maintain this value to be considered passing. The measured compression value was considered “passing” or “failing” based on the remainder of the demonstration to determine if this measured compression strength was adequate to maintain stability during extended storage operations. Although it was understood that the corrugated container does not have burst strength values that are as high as the solid fiber container, the stacking and storage tests of this demonstration provides “pass or fail” data to determine if the compression strength was high enough to maintain acceptable performance. In addition to laboratory validation of the materials and finished containers, a long term storage demonstration was to be conducted at Marengo Warehouse and Distribution Center to access the unit load compression performance of the palletized containers. Periodic warehouse audits were conducted throughout the study to assess unit load stability, signs of failure and to record overall deflection over time. The combination of laboratory testing and in-the-field validation will help reduce technical risk during integration and better ensure material performance.

3.1.3 REPULPABILITY / RECYCLABILITY EVALUATIONS

The objective of this study is to assess the repulpability of fiberboard packaging for military rations following FBA protocol, “Voluntary Standard for Repulping and Recycling Corrugated Fiberboard Treated to Improve Its Performance in the Presence of Water and Water Vapor.” This effort directly supports research activities for the Combat Feeding JSN 07-05 project “Multi-Functional Secondary Packaging.” Advancement of recyclable packaging material are provided the Warfighter with more environmentally friendly material and would also offer additional avenues of disposal to help ease logistic operations. Obtaining a report on repulpability that assesses the recyclability of coated corrugated and military specific material by Western Michigan University was a critical step in advancing the technology forward and helped provide critical scientific information on the recyclability of fiberboard packaging material.

To evaluate any of the recycled streams from its repulpability or recyclability point of view, propriety standard has to be chosen. For this study, the Voluntary Standard elaborated by FBA and the American Forest & Paper Association (AF&PA) was used to evaluate the repulpability and recyclability of moisture barrier treatments or coatings applied to liners or combined corrugated board. This was conducted in an effort to establish a minimum threshold for moisture barrier treated or coated corrugated that was intended, and labeled, to be recyclable into other paper products. From this Voluntary Standard the sample marked as repulpable has to show “Fiber yield” from the repulpability test at least 80% based on the total weight, or 85% based on the bone dry fiber charge to the pulper, where Fiber-on-fiber yield was the amount of fiber that remains after the processing action, expressed as a percentage of the fiber present in the material tested.

The solid fiberboard was deemed non–repulpable and was not suited for recycling/recovering efforts. Incorporation of new repulpable grades of fiberboard for the MRE rations would create a new avenue for disposal by creating recycling options for combat rations.

The recycling of fiberboard was a common process. It was accomplished by repulping the fiberboard and then using it in the manufacture of paper products. When fiberboard was treated with specialty substances to enhance some aspect of its performance (i.e., flame resistance, water resistance, durability), the ability of the fiberboard to repulp may be negatively impacted. V2s solid fiberboard and V3c corrugated fiberboard are manufactured with water-resistant resin in the linerboard and with water-resistant adhesive in between the sheets of the finished board. Considering the variety of methods and the qualitative nature of these tests, it was obvious that these water-resistant boards do not repulp as well as domestic board. V2s was so highly resistant to repulping that paper mills typically refuse this material. There was a very low level of repulped material and a high level of contaminates and rejected material that must be discarded. In essence, V2s was not recyclable. V3c, due to its corrugated construction, produced a higher level of repulped material than V2s. Paper mills accept V3c, especially if it was mixed with other paper/fiberboard. In essence, V3c was recyclable. It was recommended that government and military packing use domestic grade fiberboard whenever it was feasible. But it was acknowledged that, due to the extreme conditions that may be encountered during distribution and storage, the use of weather-resistant fiberboard may be required.[6] It was then highly recommended that corrugated weather- resistant fiberboard (V3c, W5c and the other grades cited in ASTM D4727) be used.

The test method in this standard has two parts: Part 1 determines the repulpability of treated corrugated by determining fiber-on-fiber yield when only the treated corrugated was processed in accordance with this standard. Part 2 determines the recyclability of the treated corrugated by evaluating its effect on mill operations and finished products when it was added to untreated corrugated in the amounts specified.

The application of this Voluntary Protocol was only for linerboard, corrugating medium, combined board, and corrugated products made from these materials, collectively known as "corrugated fiberboard." The purpose was to encourage the development of treatments to corrugated fiberboard that provides water resistance or some other desirable characteristic that results in a repulpable and recyclable structure. It was also to replace existing treatments that provided water resistance or some other desirable characteristic, but did not allow the corrugated fiberboard to be repulpable or recyclable. This standard establishes a repeatable method for simulating a commonly used subset of repulping and recycling processes. It is intended to evaluate the impact of repulping and recycling treated corrugated fiberboard on containerboard mill operations and final products. This standard establishes a method for identifying treated corrugated that can be repulped and recycled in this selected subset of processes. It establishes minimum levels of performance for the hand sheets made from treated corrugated, repulped and recycled in accordance with a detailed test protocol given in appendices. This standard was not intended to preclude the development or use of any technological advances in mill or treatment processes. It was intended to encourage the development, use and repulping and recycling of treated corrugated products for use in high-moisture environments

Data was collected from each of these tests to see the trends in comparison to the existing MRE packaging. The recyclability evaluation needs to achieve greater than 80% fiber acceptance during the recycling trials.

3.1.4 BIODEGRADABILITY EVALUATIONS

Biodegradability of the coated fiberboard materials was tested in accordance with ASTM D6868, "Standard Specification for Labeling of End Items that Incorporate Plastics and Polymers as Coatings or Additives with Paper and Other Substrates Designed to be Aerobically Composted in Municipal or Industrial Facilities". This specification establishes the requirements for labeling of materials and products (including packaging), wherein a biodegradable plastic film or coating was attached (either through lamination or extrusion directly onto the paper) to compostable substrates and the entire product or package was designed to be composted in municipal and industrial aerobic composting facilities.

3.1.5 INSECT INFESTATION EVALUATIONS

Insect resistance testing was performed where replications are to be carried in rounds of four 12 week experiments. For one container type there were 300 (10 subsamples per tote & 30 totes per round of experimentation) data points collected for the cigarette beetle trail and 120 (30 containers per round (4 rounds a year) of testing data points for the full trial. This was an excellent set of data for non-parametric data analysis protocols such as a Wilcox on Rank-Sum test. With this type of analysis it can be stated, with statistical significance (95% confidence interval), that one material type will most likely remain free from insects, under field conditions, over another material. Long term data would increase the power (alpha) and confidence interval of the test making the analysis more conclusive.

3.1.6 AERIAL DELIVERY EVALUATIONS

Aerial delivery demonstrations conducted in partnership with the Natick Warfighter Protection & Aerial Delivery Directorate and the Yuma Proving Grounds Test Center (YPG). The trials investigated the performance and survivability of existing MRE packaging systems and corrugated fiberboard packaging systems. The effort assessed the survivability of prototype packaging with a 100% examination plan that included visual inspection of test samples and identification of critical failure modes.

Aerial delivery demonstrations of MRE combat rations were also be performed in partnership with the Cargo Aerial Delivery Team, Air Delivery Directorate, and NSRDEC and with the Rhode Island Air National Guard who performed airdrops of Meal, Ready-to-Eat rations. These pallet drops were at low velocity and low altitude and included current packaging and the fiberboard structures. The primary objective of this in-the-field demonstration effort was to evaluate the system performance of experimental MRE rations packaged in recyclable fiberboard structures, assessing the overall survivability during aerial delivery operations. The drops were captured by video and many photographs were taken at all stages of the event. Environmental data recorders were integrated into each unitized load to better define the key environmental hazards; recording critical shock and vibration events during delivery and capturing altitude, pressure, humidity, and temperature profiles during handling and demonstration of the test rations. The demonstration and validation effort will assessed the survivability of the prototype packaging systems with a visual examination of each container.

The data recorders were integrated into each unit load to capture and characterize the shock profile of each unit load. The field data help identify four unique stages of aerial delivery which include cargo deployment, opening of the parachute, descent and final impact at the landing zone. The deployment phase begins as the containers fall off the aircraft ramp and immediately enters a free fall for a few seconds as the containers separate from the aircraft. The opening phase was marked by the dramatic opening of the parachute causing the load to rapidly decelerate and rotate violently. The descent was identified as a slow descent with oscillations of the unit load as it swings back and forth. The impact was the final stage of the delivery sequence and was marked with a severe impact as it hits the landing surface, often secondary impacts occur as the unit load tumbles or was dragged by the parachute. The field data recorders successfully captured each stage of the delivery process and highlighted important distinctions during delivery.

The aerial delivery demonstrations already conducted provided a tremendous amount of field data that was first of its kind, providing a more detailed baseline for environmental hazards encountered during delivery of combat rations. In addition to the captured field data, the package inspection results also helped establish a more solid baseline of survivability for the existing systems and further characterize performance of the MRE packaging systems during military unique logistics operations involving transport and distribution of combat rations. Shock/impact data collected from this study helped set baselines for aerial delivery methods and help show the correlation between varying methods of aerial delivery and their resulting impact on ration survivability.

3.1.7 DISTRIBUTION / TRANSPORTATION EVALUATIONS

The fifth objective was that the MREs withstand rough handling typically encountered within the military logistics system. This was critical for the demonstration as the MREs can experience abusive handling before arriving at their final destination for Warfighter consumption. If the packaging has any defects then the food safety was in jeopardy. MREs were tested using the following methods: ASTM D4728, D999, and D5276, to obtain the data required for this objective. The metric threshold would be less than 20% failure in comparison to the control MRE.

Vehicle Vibration

The test method and levels for this schedule are intended to determine the ability of shipping units to withstand random vibration during transport. For this section of the test plan, each pallet load shall be fitted with another pallet in a double-stack configuration (if double-stack shipping was applicable for the packaging configuration). The top pallet should be loaded with a concentrated dead weight load equal to the weight of the lower pallet. This will simulate a double stack of units in transport, which was valid for certain package configurations listed herein. The test will be conducted using random vibration on the shipping units using the PSD (power spectral densities). For vertical vibration, the test conducted for 3 hours on a vertical motion vibration machine. If transverse and longitudinal vibrations are possible causes for damage, vibration testing were conducted on a horizontal motion vibration machine for 3 hours in each axis.

The sixth objective was the survival of the MREs after transportation and distribution. The MREs were subjected to air drops, extreme environmental conditions, and a rigorous transportation route which was relevant for this demonstration plan to assure survival in all types of distribution and transportation scenarios. An official inspector was needed to simply evaluate the packaging for defects after the MREs have undergone the various distribution and transportation scenarios. A 10% failure rate was acceptable for this objective.

3.1.8 WASTE-TO-ENERGY / EMISSIONS EVALUATIONS

The Army was now evaluating waste-to-energy as an alternative to waste disposal than burn pits. Studies were done at with Infoscitex. Emissions studies were performed with the EPA who has worked in this area of emissions and burn pits.

The seventh objective was the evaluation of whether the fiberboard can be processed in the waste to energy converter and characterization of the current and new fiberboard to see if any toxic materials are given off during emissions. The seventh objective was the evaluation if the fiberboard can be processed in the waste-to-energy converter and that the emissions are characterized for the current and new fiberboard to see if any toxic materials are given off.

IST was the prime contractor on the Battalion Waste-to-energy Converter (BWEC) program, which was focused on the development and demonstration/evaluation of a prototype system meeting targeted system performance and physical specifications. IST conducted a study on the impact of new fiberboard materials on waste-to-energy conversion systems performed in conjunction with the planned BWEC demonstration activity at Fort Benning GA.

3.1.9 SOLDIER ACCEPTANCE / MRE FOCUS GROUP / FIELD STUDY

Annual field evaluations supported under CFD FIRIP were conducted for the MRE rations. The new packaging designs were evaluated to obtain Warfighter feedback and address any possible issues encountered during field feeding activities. This effort addressed qualitative performance objectives outlined in Section 3.1, and obtained critical customer feedback and end user information that better defines the interaction between the customer and new packaging designs. The focus group included a large assembly of soldiers ranging from 25-100 participants, who were surveyed on new packaging configurations and food products for acceptability, usability and human factor considerations. The field evaluations also helped gather critical information on food preparation, eating behaviors, and consumption/waste observed in relevant training environments and circumstances similar to those in which rations are intended to be consumed.

The assessment data management approach, developed by NSRDEC researchers on the Consumer Research / Cognitive Science Team, utilized surveys/questionnaires to capture pertinent end user comments and viewpoints from each participant. Questionnaires consisted of rating scales, multiple choice questions, and write-in areas for open-ended comments to help collect the following information: ease of use, overall taste, durability in relevant environments, mission/task acceptability, and recommended design improvements. NSRDEC researchers integrated the questionnaire data into Statistical Package for Social Sciences (SPSS) spreadsheets, and analyzed to calculate and report descriptive statistics. Frequency tables of responses were be compiled for multiple choice questions, and mean rating scores were computed for rating scale questions. The field evaluations provided critical qualitative research data and capture valuable customer knowledge in an effort to optimize combat rations and packaging technologies for the Warfighter.

3.1.10 MANUFACTURING EVALUATIONS

The Qualitative Performance Objectives are the ease of processing and packaging. This was important as the containers need to be fabricated on commercially available equipment that are already utilized by current converters. All of the co-packers must be able to adapt to this new packaging and gain acceptability. The co-packers gave feedback on the filling and the packing of the MREs into the fiberboard shipping containers. Also, the co-packers did end item inspection and issue a certificate of conformance.

The Qualitative Performance Objective for these evaluations was to ensure the manufacturability of the corrugated ration containers at the paper and containers production facilities. These evaluations are important as the coated paper and containers need to be made on commercially available equipment that the converters currently have at their production locations. As specified in Table 3, the inspection of the manufacturing process and the final converted materials were conducted according to manufacturing specifications in ASTM D4727 (Standard Specification for Corrugated and Solid Fiberboard Sheet Stock (Container Grade) and Cut Shapes) as well as ASTM D5118 (Standard Practice for Fabrication of Fiberboard Shipping Boxes). Feedback from the manufacturers during the production of the fiberboard was also be critical as any changes in the production process would affect the final cost of the end item as well as the acceptability of the manufacturer to produce these items in their facility.

3.1.11 MRE ASSEMBLY EVALUATIONS

The Qualitative Performance Objectives for these evaluations are to ensure ease of packing of the ration components into the corrugated containers at the co-packer's facility. All of the co-packers must be able to adapt to this new corrugated container packaging and gain acceptability on their production line. The co-packers provided feedback on the filling and the packing of the ration items into the corrugated shipping containers. Co-packer feedback was requested for acceptability on equipment used to seal and glue the individual containers as well as their ability to print on the containers using their existing printing capabilities. The co-packers also did end item inspection and issue a certificate of conformance for the Army Veterinary Food Inspection Specialist Board to review. Success criteria of this evaluation depend on the acceptability and conformance of the corrugated containers by the individual co-packers.

4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

The NSRDEC has state of the art, annually calibrated equipment and clean laboratories, which were used for the demonstration. Laboratory testing was conducted at the NSRDEC Center for Advanced Materials and Polymers (CAMP).

As the Lead Service Activity for fiberboard boxes and sheet stock, barriers, bags and sacks, adhesives, the Logistic Support Activity (LOGSA), Packaging Storage and Containerization Center (PSCC), Packaging Applications Test Facility was well equipped to perform testing of MRE meal bag packaging and secondary shipping containers. For that reason, they were chosen by the Natick Soldier Research, Development & Engineering Center (NSRDEC) to analyze the weight and performance of the packages.

Repulpability/Recycling testing were conducted by Western Michigan University's (WMU), Department of Paper Engineering, Chemical Engineering and Imaging to examine the repulpability and recyclability of fiberboard packaging following FBA protocol, "Voluntary Standard for Repulping and Recycling Corrugated Fiberboard Treated to Improve Its Performance in the Presence of Water and Water Vapor". This was a critical step in advancing the technology forward and providing technical insight into the overall recyclability of fiberboard packaging. Recycling trials utilizing the fiberboard containers were performed to ensure that all components of the fiberboard can be processed on commercial recycling equipment. Waste-to-energy converter trials were performed with Infoscitex.

Biodegradability testing according to ASTM D6868 were conducted at Advanced Materials Center Inc. in Ottawa, Illinois. Advanced Materials Center, Inc. was an independent full service laboratory providing a wide range of unique services to all sizes of corporations and laboratories. AMC's areas of concentration and expertise are in environmental, materials and product evaluations and testing, including product litigation. Advanced Materials Center Inc. was also a certified laboratory by the Biodegradable Products Institute.

Moses Biologic (MBL) was chosen for the insect infestation studies as the entomologist, Mr. Jade Vardeman, has expert experience in this field and was a student of Mr. Michael Mullen who has routinely performed insect testing for MREs for the past 20 years and was also a consultant to MBL. MBL was equipped with a 3500 sq. ft. warehouse facility in South Carolina which includes: five - 8x6 ft. environmental chambers, one - 16x8 ft. environmental chamber, one - 4x4 ft. environmental chamber and two - Precision upright environmental cabinets

Air Drop demonstrations and evaluation were conducted at YPG, in Yuma, AZ. YPG was one of the DoD's largest land holders, with state-of-the-art facilities and was the Army's desert environment test site, where demanding terrain and extreme heat combine to challenge equipment/material in real-world conditions. The Yuma Test Center was currently a multi-purpose test complex and was the primary site for airdrop analysis of military rations. The aerial delivery demonstrations of corrugated packaging systems was conducted at the Yuma Test Center in partnership with the airdrop delivery team at NSRDEC. The test center offers sufficient resources to accurately record vertical decent rate, GPS data and impact shock of test systems. The center also has multiple video recording sites that are capable of recording demonstration trials from aircraft extraction to final impact on the ground. Additional demonstration trials may also be performed at the Rhode Island National Guard base to assess low altitude free fall survivability of the prototype containers.

Emission testing of burning containers was conducted with Dr. Brian Gullett of the United States EPA, National Risk Management Research Laboratory in Research Triangle Park, North Carolina. The research laboratory was equipped with an open-burn test facility while larger burns can be conducted along with Tooele Army Depot in Utah and the Air Force Institute of Technology.

The waste-to-energy trials were performed by Infoscitex, Waltham, MA. This work leveraged an existing project with NSRDEC entitled “Battalion-Scale Waste-to-Energy Conversion System for Contingency Base Camps” that was executed by Infoscitex Corporation, and MSW Power Corporation. Infoscitex Corporation (IST) and subcontractor MSW Power have developed a prototype battalion-scale waste-to-energy converter (BWEC) system. The BWEC system takes mixed solid waste generated from these basecamps and, through a downdraft gasification process, converts it to a high energy content syngas which can then be used to fuel a modified diesel generator. Instead of going to an incineration operation or landfill, the BWEC system processes the waste and converts it to usable electricity, thereby reducing the installation’s dependence on fossil fuels to operate generators. The BWEC system with fiberboard was tested one-week at Fort Benning Georgia.

The Transportation / Distribution trials were demonstrated in several shipment trials focused on over-the-road transport from AmeriQual Packaging in Evansville, Indiana to various military installations throughout the United States. Fort Bliss, located in El Paso, Texas and Joint Base Elmendorf-Richardson near Anchorage, Alaska were used as end user storage locations and represent environmental extremes for field demonstration. Fort Greely, Alaska may also be used as a potential shipment destination which was home to the Cold Regions Test Center (CRTC). Fort Greely is located in one of the coldest areas in Alaska, and can accommodate cold, extreme cold or temperate weather tests depending on the season. Shipments of prototype packaging were inspected by NSRDEC packaging engineers and Veterinary Command (VETCOM) inspectors to conduct a full assessment of material/system performance. Data recorders were also be utilized during shipment to characterize the hazards (shock, impact, vibration, temperature) encountered during over-the-road transport activities.

Long-term storage demonstrations were conducted at military storage sites such as the Marengo Warehouse and Distribution Center located in Marengo, Indiana to assess the unit load compression performance of the palletized containers. The center has twelve individual warehouses, totaling in excess of 1,300,000 sq. ft. When fully developed, the interior housed twenty-eight warehouses, totaling over 3,000,000 sq. ft. of modern storage space with a consistent temperature range of 56 – 60°F. The distribution center was a key underground storage site for the DoD and was the proposed demonstration site for the long term storage demonstration of unitized MRE loads. Periodic warehouse audits were conducted throughout the study to assess unit load stability, signs of failure and to record overall deflection over time. Static load laboratory demonstrations were also be concurrently performed to assess the impact of temperature, humidity and cyclic conditions on unit load compression performance and would follow ASTM D4577, “Compression Resistance of a Container under Constant Load”.

Field testing occurred at Fort McCoy in Wisconsin. Pallets for MREs being stored at Fort Bliss, Texas, during the summer time high heat and transported through different elevations were shipped to Fort McCoy. The training area was in a temperate climatic region of the continental U.S. with daytime highs between 70 and 80°F. The training area was outside the main garrison area and, with the exception of access via dirt roads, was otherwise an unimproved area without buildings or other forms of shelter. Soldiers participating in this final phase of testing transported the rations to the field site; handling them in the typical rough manner (i.e. cases thrown from soldier to soldier, thrown from the vehicle to the ground). All activities took place in the open including the consumption of the rations for lunch time meals. NSRDEC had a relevant field test operation occurring at the same time as the ESTCP demonstration. This was advantageous since the personnel are already there to work on the demonstration and evaluate/inspect the MREs.

York Container, located in York, Pennsylvania, was the site location to test the manufacturability of the prototype containers at the container production level. York Container was established in 1954 and focuses on the manufacturing of shipping containers and displays. Their core competencies of managing packaging requirements, evaluating a product line, developing new shipping systems and providing structural solutions make them an ideal location to test the manufacturability of the prototype containers.

AmeriQual LLC, located in Evansville, Indiana, was the site location for all case packaging and assembly trials and was also the origin of shipment for the distribution demonstration testing outlined in the demonstration plan. AmeriQual was a leader in food processing, packaging and assembly that specializes in the production, packaging, assembly and distribution of high-quality, shelf-stable food products for the DoD and major branded food companies. They are a current supplier of the MRE rations to the government and were an ideal test location for the new prototype containers.

4.2 PRESENT OPERATIONS

Currently, MRE SF shipping containers are manufactured using solid fiberboard material consisting of two outer facings of 90 lb wet strength linerboard and an inner ply of 69 lb linerboard. The fiberboard container was constructed according to RSC-L, of ASTM D5118/D5118M and grade V2s of ASTM D4727/D4727M. The current solid fiberboard materials are produced by International Paper’s Industrial Packaging Group. The solid fiber materials are designed to be strong and moisture resistant as a cost savings replacement for packaging materials such as wood, rubber, plastic, or polystyrene foam. Currently, corrugated containers are not used for this application as they are typically not as strong and are less moisture resistant than the solid-fiber boxes. These materials are typically made in a similar process as the corrugated process, but without the need for a corrugation unit. These processes typically use wet-strength additives in the board which enhances the strength of the material under wet conditions. These additives have been found to be non-repulpable by industry standards and therefore increase solid-waste generated by secondary packaging.

4.3 SITE-RELATED PERMITS AND REGULATIONS

All NSRDEC laboratories are inspected quarterly to comply with established safety procedures and policies governed by EPA and OSHA. NSRDEC was not aware of any permits or potential regulations needed for the field study, laboratory testing and transportation/distribution trials. All safety and regulations at the Army bases were adhered to and NSRDEC employees would abide by any safety regulations at all installations and test sites. For example, YPG requires site permits for access to specified drop zones and permits/passes for all data recorders and cameras. The appropriate forms were submitted and completed by all NSRDEC employees prior to testing at YPG.

5.0 TEST DESIGN

5.1 REDUCTION OF SOLID WASTE-ASSESSMENT OF WEIGHTS

In the 1990's the DoD instituted the National Technology Transfer and Advancement Act of 1995. The Act requires that the military use voluntary consensus standards wherever possible. By communicating with industry and developing consensus standards, the military was aware of the producers' manufacturing needs, as well as supply shortages, which can impact regulations or procurement processes. Furthermore, the Act puts more emphasis on performance-based standards and specifications to allow for more opportunities for commercial producers to supply innovative products and removes the military from the role of dictating requirements. Additionally, with the onset of new technologies and the ability to store data, data-driven decisions have become a focus of the federal government. The government needs to validate that the decisions are being made based on accurate data. However, this sometimes requires that the performance capabilities of current systems as well as new designs be examined for comparison when the performance data of the more current systems do not exist. This may mean that the government has to collect data through testing prior to performing a statistical analysis to make a decision.

In an attempt to save the government money, packaging was an area with increased focus. In the past, many things were over-protected to ensure that whatever assets or materials were being shipped, were received by the warfighter in the best possible condition. This over-protection called "over packing" can lead to pricey logistics and costly mitigation of wasted packaging materials. By striking a balance between protection of the asset and overall amount of packaging, the logistic costs and environmental impact can be reduced. In order to reduce the logistical burden on the warfighter as well as during the distribution cycle, Meals-Ready-to-Eat (MRE) packaging was getting remodeled. The project examined the materials used in the packaging and attempts to select the packaging that minimizes the overall size and weight of the packages.

The study examines the weight reduction by changing outer box material from the solid fiberboard to corrugated fiberboard and by changing Meal bag from the current pull-apart blown meal bags with thermoformed inner bags to a single thermoform bag capable of meeting the same requirements for performance as the current assembly.

Containers of each of the six configurations were weighed and tested in accordance with American Society for Testing and Materials (ASTM) D4169, Standard Practice for Performance, Testing of Shipping Containers and Systems, Distribution Cycle 18 (DC-18). The two configurations include:

(1) Current Solid Fiberboard box with Current Meal Bag, (2) ECTSP corrugated box with Current Meal Bag,

5.1.1 Weight Analysis

Three containers were weighed in the “as received” condition which was sealed with contents, and strapping in place. The containers were weighed without strapping and also without contents. Each meal bag was opened and the contents were verified and the bag was weighed without contents. Each of these questions will be answered.

Question 1. What was the weight difference between the outer box made from solid fiberboard and the outer box made from corrugated fiberboard?
Question 2. Are there any other factors that are attributing to weight difference, such as case or interaction effects?
Question 3. Which assembly has the least number of defects when tested in accordance with ASTM D4169, Standard Practice for Performance Testing of Shipping Containers and Systems? Can the weight of the packaging be decreased while maintaining current performance levels?

The variables of interest are:
Overall Weight
Explanatory Variables – Outer Box (Solid or Fiberboard), Case (A or B), Meal Bag (Current
Response Variable – Weight

Outer Box Weight
Explanatory Variables – Outer Box (Solid or Corrugated), Case (A or B) Response Variable – Outer Box Weight

Assembly Performance
Explanatory Variables: Outer Box (Solid or Corrugated)
Response Variable – Number of Defects

Analysis of Weight
NOTE: 12 meal bags in each case were measured.

5.2 PERFORMANCE TESTING

Logistics Support Activity (LOGSA) Packaging, Storage, and Containerization Center (PSCC) was contacted by (NSRDEC) to conduct Transportation, Handling and Environmental testing of Meal, Ready-to-Eat (MRE) packages in support of the Lightweight and Compostable Fiberboard, Environmental Security Technology Certification Program (ESTCP). As the Lead Service Activity for fiberboard boxes and fiberboard sheet stock, LOGSA's Test Facility was well equipped to perform transportation testing of fiberboard specimens. The test parameters were established to evaluate the ability of the package to withstand typical military and commercial transportation stresses and environments. Data gathered was used by NSRDEC to evaluate any benefits of the corrugated fiberboard case material.

5.2.1 Unitized Load

5.2.1.1 Test Items

Each test sample consisted of 48 cases unitized on wooden pallet. The unitized loads were packaged in accordance with DLA Troop Support Form 3507 (October 2010), Type I, Class C. The samples were tested in the as-received condition.

Solid Fiberboard cases (Control Sample)

Unitized load Dimensions: 43″X51-1/2″X41-1/2″
Test Weight: 1060 lbf (measured at Std. conditions)

a)

b)

Figure 8. a) Solid Fiberboard Unitized Load and b) Solid Fiberboard Case

Corrugated Fiberboard cases

Unitized load Dimensions: 43-3/4″X52″X41-3/4″
Test Weight: 1043 lbf (measured at Std. conditions)

a) **b)**

Figure 9. a) Corrugated Fiberboard Unitized Load and b) Solid Fiberboard Case

5.2.1.2 Test Sequence

Table 5. identifies each test, and the respective standard that was followed to perform the test. The test results were described in detail in the following sections.

Table 5. List of Tests Performed

Quantity of Test Samples	Environmental Conditions	Test In accordance with	Test details
1 Corrugated 1 Solid	Standard	Warehouse Stacking per ASTM D4169 - Schedule B	Stack Load was based on stack height of 4 pallets and an F factor of 3.15 (based on a shipping unit construction F factor of 4.5 with a full pallet load reduction of 30%)
1 Corrugated 1 Solid	High Humidity		
1 Corrugated 1 Solid	Standard	Bridge Impact per ASTM D4169 - A1.2.2.2(4)	Impact Velocity of 7.3 ft./sec 4 impacts per sample Utilization of a 100X100 mm impact hazard.
1 Corrugated 1 Solid	Standard	Rotational Drop Testing per ASTM D4169 - Schedule A	8 Drops per test sample
1 Corrugated 1 Solid	High Humidity		

5.2.1.3 Compression Testing

The objective of this test was to ensure that the unitized load was capable of withstanding the compressive loads that occur during warehouse storage. To simulate different storage conditions, two pallets in each configuration was tested, one at standard conditions (23 ±2°C at 50% RH) and one at high humidity (25°C at 90% RH).[7,8,9]
Each test sample was inspected prior to testing to ensure the packaging was in accordance with DLA Troop Support Form 3507 (October 2010), Type I, Class C.[10] Two test samples (one control sample and one corrugated sample) were placed into standard conditions (23°C & 50% RH) for 48-hours, and an additional two test samples (one control sample and one corrugated sample) were placed into high humidity conditions (25°C & 90% RH) for 48 hours. Following the conditioning period, the tests were conducted in accordance with ASTM D4169 Schedule B (Warehouse Stacking). The target load was calculated using the criteria specified in Para. 11.2 of ASTM D4169.

$$L = M \times (H-1) \times F \times (1-r)$$

Where L= Computed load (lbf)

M = mass of one shipping unit = 1,100 lbf (Rounded up from measured values)

H = Maximum height of stack in storage (number of containers high) = 4 (as specified by NATICK)

F = A factor used to for the appropriate container construction = 4.5 (from test level table, construction type 2, assurance level I)

r = full pallet factor reduction = 30% (.30)

$$L = 1{,}100 \times (4-1) \times 4.5 \times (1-.30)$$
$$= 1{,}100 \times 3 \times 4.5 \times .70$$
$$= 10{,}395 \text{ lbf}$$

Each test sample was placed individually onto a compression test machine (Figure 10 and Figure 11). The top platen was lowered at a rate of ½” per minute until the target load was reached. The load was maintained for approximately 3 seconds in order to inspect the package for any damage.

Figure 10. **Compression Test of Corrugated Fiberboard Cases**

Figure 11. Compression Test of Solid Fiberboard Cases

5.2.1.4 Inclined Plane Testing

Inclined impact tests are dynamic tests performed to determine the stability of the unitized load, the durability of its construction and its ability to withstand lateral impact forces within the handling and shipping environment. Each test sample was inspected prior to testing to ensure the packaging was in accordance with DLA Troop Support Form 3507 (October 2010), Type I, Class C. Two test samples (one control sample and one corrugated sample) were placed into standard conditions (23°C & 50% RH) for 48-hours. The inclined impact test (Figure 3-7) utilizes a guided test carriage, which impacts a perpendicular solid backstop. A 100mm X

100mm timber was firmly attached to the backstop and used as an impact hazard. The timber was placed in order to contact the lower edge of the package. A test sample was set on the leading edge of the carriage, and raised to a height that achieved an impact velocity of 7.3 ft./s as required by ASTM D4169 [A1.2.2.2(4)]. Each test sample was impacted on each of its four sides.

Figure 12. Incline Impact Test

5.2.1.5 Rotational Edge and Corner Drop Testing

The objective of this test was to ensure that the unitized load was capable of withstanding the vertical dynamic forces that occur during transportation. To simulate different environmental conditions, two pallets in each configuration were tested, one at standard conditions (23 ±2°C at 50% RH) and one at high humidity (25°C at 90% RH).

Each test sample was inspected prior to testing to ensure the packaging was in accordance with DLA Troop Support Form 3507 (October 2010), Type I, Class C. Two test samples (one control sample and one corrugated sample) were placed into standard conditions (23°C & 50% RH) for 48 hours, and an additional two test samples (one control sample and one corrugated sample) were placed into high humidity conditions (25°C & 90% RH) for 48 hours. Following the conditioning period, the tests were conducted IAW ASTM D4169 [A1.2.2.2 (3)]. For all rotational drop tests, a drop height of 12″ was used based on the gross weight of the test sample of over 1000 lb. at an assurance level I.

The edge drop tests were conducted IAW and ASTM D6179 Method A with a 6″ timber edge support as shown in Figure 13. The opposite edge was raised to 12″, then released onto a rigid steel plate embedded in concrete. The corner drop test was completed per ASTM D6179 Method

B as shown in Figure 14 with exception, that one corner was supported on a 6″ high block while the other corner rested on a 12″ high block.

Figure 13. Rotational Edge Drop

Figure 14. Rotational Corner Drop

Table 6. Test Equipment

Item	Manufacturer	Model No.	Serial No.	Calibration Expiration Date
Digital Scale 5,000 lb.	Fairbanks Scales	FB2200-2	081710 200045	3/15
10'x10', Environmental Simulation Chamber, 50 °F to +180 °F, 10% to 95% RH	Tenney, a product brand of SPX Thermal Product Solutions	WITR	0712000051	4/17
10'x10', Environmental Simulation Chamber, -50 °F to +220 °F, 10% to 95% RH	Tenney, a product brand of SPX Thermal Product Solutions	WITR	0712000052	4/17
Incline Impact Tester	L.A.B. Equipment Inc. Franklin Park, IL	6,000-OT	271026	N/R
Quick Release Mechanism, 3,000 lb	Lansmont Corp.	QR-3000	N/A	N/R
Compression / Tensile Tester (Range: 0 to 60,000 lbf)	SATEC Systems Inc.Unidrive, Grove City Pa.	MKIV 60UD	1105	1/17
Chart Recorder	Omega Engineering Inc.	CTXL-TRH-W	13096053	5/17

5.2.2 Case Level Performance Testing

5.2.2.1 Test Items

The containers are fiberboard secondary MRE shipping containers intended for government shipping filled with 12 individual meal bags. Secondary Packages are either Case A or Case B for the specific meal variety included. The shipping containers were either the current solid fiberboard or corrugated fiberboard developed through the ESTCP project

1. Current Solid Fiberboard box with Current Meal Bag
2. ESTCP corrugated box with Current Meal Bag

Three containers of each configuration were used to analyze the weight and three more of each configuration were used to test the performance. At least one container of each menu variety (Case A and Case B) were selected for weight analysis and performance testing. The third case for each group was selected at random. The containers selected for testing were placed in standard conditions, 50.0% ± 2.0% RH and 23.0 ± 1.0°C in accordance with ASTM D4332, where it was inspected. No transit-induced damage was observed.

5.2.2.2 Performance Testing

To assess performance of the configurations, the packages were tested in accordance with ASTM D4169, Standard Practice for Performance Testing of Shipping Containers, Distribution Cycle 18 (DC-18). [11] The containers were tested to Assurance Level I, which was a high level of test intensity required for Level A packaging in accordance with MILSTD-2073-1E as was required for MREs.[10] The test equipment used in the testing was shown in Table 7. The DC-18 testing includes a sequence of testing that could be encountered throughout the lifecycle of the container and was shown in Table 8.

Table 7. Test Equipment

Item	Manufacturer	Notes/Test Used On
2,200 g Balance, Mdl MSA2203S000DE, SN 0026404691	Sartorius C/O ITIN Scale Co., Brooklyn, NY	Weight
Digital Scale, 250 kg/500 lb., Mdl BIOS T51P, SN 0024060-6BN 1G03311	Ohaus Corp.	Weight
Rain Room	N/A (Constructed on site)	Environmental
10'x10' Chamber (Ranges: -50 °F to +220 °F / 0% to 95% RH), Mdl WITR-5095, SN 0712000052	Thermal Product Solutions	Conditioning, Environmental
10'x10' Chamber (Ranges: -50 °F to +180 °F / 10% to 95% RH), Mdl WITR, SN 0712000051	Thermal Product Solutions	Conditioning, Environmental
12'x10', Chamber (Range: -80°F), Mdl 4779, SN 564200182	CRYO-Chem Inc. (Tenney Engineering Inc.)	Environmental
Altitude Simulation Chamber (0-80,000 ft), Mdl EAH64-2-7.5WC, SN 03025605	Envirotronics, Grand Rapids, MI	Low Pressure
Free-fall Drop Tester, Mdl PDT56ED, SN M14198	Lansmont Corp., Monterey, CA	Manual Handling
Transportation Simulator, Mdl 1250V, SN 241121	L.A.B. Equipment Inc., Franklin Park, IL	Loose Load Vibration
Transportation Simulator, Mdl 2000V, SN G23605	L.A.B. Equipment Inc., Franklin Park, IL	Loose Load Vibration
Transportation Simulator, Mdl 6000V, SN 241277	L.A.B. Equipment Inc., Franklin Park, IL	Loose Load Vibration
Compression Tester, Mdl Squeezer, SN M-17672	Lansmont Corp., Monterey, CA	Warehouse Stacking
Hydraulic Random Vibration System, Mdl HV60x60, SN	Lansmont Corp., Monterey, CA	Vehicle Vibration (Repetitive Shock)

Table 8. ASTM D4169, DC-18 Test Sequence

Reference	Sequence	Schedule	Description	Method
A1.2.1	1	A	Manual Handling, Small shipping Units	ASTM D5276
A1.3	2	B	Warehouse Stacking	ASTM D642
A1.2.1	3	A	Manual Handling, Small shipping Units	ASTM D5276
A1.4	4	I	Low Pressure (High Altitude)	ASTM D6653
A1.5	5	H	Environmental Hazard	ASTM D951 (water spray)
A1.6	6	F	Loose Load Vibration, Repetitive Shock	ASTM D999 Method A2
A1.7	7	-	Vehicle Vibration, Repetitive Shock	MIL-STD-810F
A1.2.1	8	A	Manual Handling, Small shipping Units	ASTM D5276

Prior to each test sequence, containers were conditioned at 23°C ± 1°C and 50 ± 2% RH in accordance with ASTM D4332.[12] The failure criteria was any exposure of contents or opening of the container.

5.2.2.3 Free Fall Drop Test. From each of the six configurations, three shipping containers were required to be subjected to Test Method ASTM D5276.[13] Containers were dropped from a height of 30 inches. The containers were dropped in the following sequence of orientations: Face 1, Edge 3-5, Edge 3-4, Corner 3-5-2, Corner 3-4-6, and Face 3.

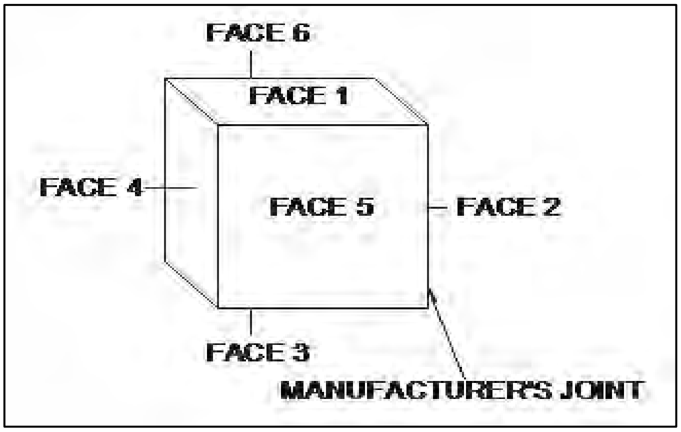


Figure 15. Box Member's per ASTM D5276

Figure 16. Free Fall Drop Test from 30 inches

5.2.2.4 Warehouse Vehicle Stacking (A1.3)

Compressive Resistance of Shipping Containers. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D642.[5] For vehicle stacking made up of identical shipping units, the shipping unit was loaded to the computed load value, as calculated below. Remove the load within 3 seconds after reaching the specified value.

$$LL = MM_{ff} \times JJ \frac{ll \times ww \times h}{KK} \frac{HH - h}{h} \times \times FF$$

L = Computed Load, lbf

M_f = Shipping density factor, lb./ft^3 (25) J
= 1 lbf/lb.
H = maximum height of stack in storage or transit vehicle (54 inches) h =
Height of shipping unit or individual container, in inches
F = factor assurance level to account for combined effects of alignment, warehouse conditions, and previous handling (8.0)

The calculated load was 800 lbs

Figure 17. MRE Under Stack Test

5.2.2.5 Free Fall Drop Test. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D5276. Containers were dropped from a height of 30 inches. The containers were dropped in the following sequence of orientations: Edge 4-6, Face 5, Face 4, Corner 1-2-6, Edge 1-6, and Corner 1-5-2.

5.2.2.6 Altitude Test. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D6653.[14] Increase altitude at an approximate rate of 1,000 -2,000 feet per minute until 15,000 feet was reached. Hold for 60 minutes. Release the vacuum at an approximate rate of 1,000 -2,000 feet per minute.

Figure 18. MREs in Altitude Chamber

5.2.2.7 Water Spray Test. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D951.[15] Prior to testing, containers were conditioned at 23°C ± 1°C and 50 ± 2% RH in accordance with ASTM D4332. Each samples should be weighed before testing and immediately after completion of the final cycle. The environmental hazards were tested at the following parameters with spray intensities of 4 ± 0.5in./h:

Table 9. Environmental Cycle

Temperature ºF	Water Spray	Duration (hours)
160		16
55	X	2
-5		2
125	X	2
55	X	2
32		16
160		4
55	X	2
-65		2
160		16
55	X	2
-65		2
40		3
160		16

Figure 19. MREs Under Rain Test

Figure 20. MREs in -65°F Conditions

Figure 21. MREs in 160°F Chamber

5.2.2.8 Rotary Synchronous Vibration Test. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D999, Method A2 (Rotary Motion).[16] Prior to testing, containers were conditioned at 23°C ± 1°C and 50 ± 2% RH in accordance with ASTM D4332.[12] The container were tested for 2 hours on its base and 1 hour on its long side.

Figure 22. MRE on Loose Load Vibration Table

5.2.2.9 Random Vibration Test. Mount the test specimen in accordance with A1.7.3 and conduct random vibration test for 3 hours in accordance with the power spectral densities assigned to each axis (totaling 9 hours).

Table 10. Power Spectral Densities

Vertical		Traverse		Longitudinal	
Frequency (Hz)	PSD (g2/Hz)	Frequency (Hz)	PSD (g5.3.111/Hz)	Frequency (Hz)	PSD (g2/Hz)
10	0.01500	10	0.00013	10	0.00650
40	0.01500	20	0.00065	20	0.00650
500	0.00015	30	0.00065	120	0.00020
		78	0.00002	121	0.00300
		79	0.00019	200	0.00300
		120	0.00019	240	0.00150
		500	0.00001	340	0.00003
				500	0.00015

Figure 23. MREs during Random Vibration

5.2.2.10 Free Fall Drop Test. From each of the six configurations, three shipping containers shall be subject to Test Method ASTM D5276. Prior to testing, containers were conditioned at 23°C ± 1°C and 50 ± 2% RH in accordance with ASTM D4332.

Containers were dropped from a height of 30 inches. The containers were dropped in the following sequence of orientations: Face 1, Edge 3-5, Edge 3-4, Corner 3-5-2, Corner 3-4-6, and Face 3.

5.3 Repulpability / Recyclability

5.3.1 Fibre Box Association Certification

Western's recycle plant was a certified laboratory for the Fibre Box Association certification test protocol for wax treatment replacement corrugated containers. This was a voluntary standard for repulping and recycling corrugated fiberboard treated to improve its performance in the presence of water and water vapor. The corrugated industry developed this recyclability standard that allows these wax alternatives to be tested, proven and certified recyclable if they pass the required protocol.

Fiber-on-fiber yield was the amount of fiber that remains after the processing action, expressed as a percentage of the fiber present in the material to be tested. Handsheets are sheets made from a suspension of fibers in water in an operation, whereby each sheet was formed separately by draining the pulp suspension on a stationary sheet mold. OCC (Old Corrugated Containers) was a grade of waste paper comprised of untreated corrugated boxes that have been used for the purpose for which they were originally purchased and have subsequently been source separated from other waste. Recyclable means used paper, including in-plant and post-consumer waste paper and paperboard, which was capable of being processed into new paper or paperboard using the process defined in this standard. Recyclability test sample consisted of a minimum of 20% (by weight) of the treated corrugated to be tested and the remainder of the untreated corrugated. Repulpable means the test material that can undergo the operation of re-wetting and fiberizing for subsequent sheet formation, using the process defined in this standard. Treated corrugated was the linerboard, corrugating medium, combined board or corrugated products that have been subjected to a specific treatment for the purpose of improving its performance in the presence of water or water vapor. The level of treatment used in the test must be equal to or greater than the level of treatment to be used in the field. Untreated corrugated/control was the same linerboard, corrugating medium, combined board or corrugated products that have not been subjected to any treatment to improve performance in the presence of water or water vapor.

5.3.1.1 Test Method: Before beginning the test protocol, determine the moisture content of the treated corrugated samples.

5.3.1.1.1 PART 1: Repulpability

A 100% charge of treated corrugated was repulped in a Modified Waring Blender and a British Disintegrator in water at a pH of 7 (±0.5 pH) that was maintained at 125°F (±10°).

The pulped material was separated in a screen with 0.010-inch or smaller slots to determine fiber recovery as a percentage of the amount of fiber charged.

5.3.1.1.2 PART 2: Recyclability Mix a minimum of 20% treated corrugated and the remainder of the same untreated corrugated in a laboratory-scale pulper at pH 7 (±0.5 pH) and 125°F (±10°). This was the recyclability test sample. As a control, a charge of 100% of the same untreated corrugated was also pulped using identical conditions. Each pulped material was passed through (in succession) a pressure screen equipped with a basket with 0.062 inch holes, the same screen or a similar screen equipped with a basket with 0.010 inch slots and a reverse centrifugal separator under conditions specified in the procedure.

Handsheets (3.0 gram) are made from the final stage (cleaner) accepts. For each batch tested, the handsheets are pressed and dried with heat and tested for product performance properties. Properties include slide angle, short span compressive strength (STFI), bursting strength and water drop penetration, using the established TAPPI official test methods. The final sheets shall have no more than 15 spot counts, or not exceeding 30% greater counts than the control, with an area of ≥ 0.4 mm2 area, averaged over 3 sheets. The properties and appearance of the handsheets from the recyclability test sample and untreated corrugated tests will be compared.

5.3.1.1.3 PART 3: Performance Levels

Treated corrugated satisfying all of the requirements of the voluntary standard will be regarded as repulpable and recyclable. There are three general performance requirements: fiber yield, operational impact and product requirements.

Fiber yield from the repulpability test must be at least 80% based on the total weight, or 85% based on the bone dry fiber charge to the pulper.

Operational impact was acceptable if:

The entire procedure can be completed without using an acid wash to clean the flat screen in the Repulpability Test or dismantling the pressure screens to clean them before finishing the Recyclability Test, and there was no visible deposition on any part of the disintegrator

Product requirements are satisfied if:

The appearance of the handsheets made from the recyclability test sample shows no substantial difference from that of the handsheets made from the control and the spot count was ≤ 15 counts, or not exceeding 30% greater counts than the control, with an area ≥ 0.4 mm2, averaged over 3 sheets.

The decrease in the slide angle of the handsheets (the average of five first slides) made using the recyclability test sample from the slide angle of the handsheets made from the control must be no greater than 15%.

STFI and burst strength of the handsheets made using the recyclability test sample, normalized to the sheet basis weight, must show no more than a 10% decrease from the respective values for the control. All test results are to be reported in English units.

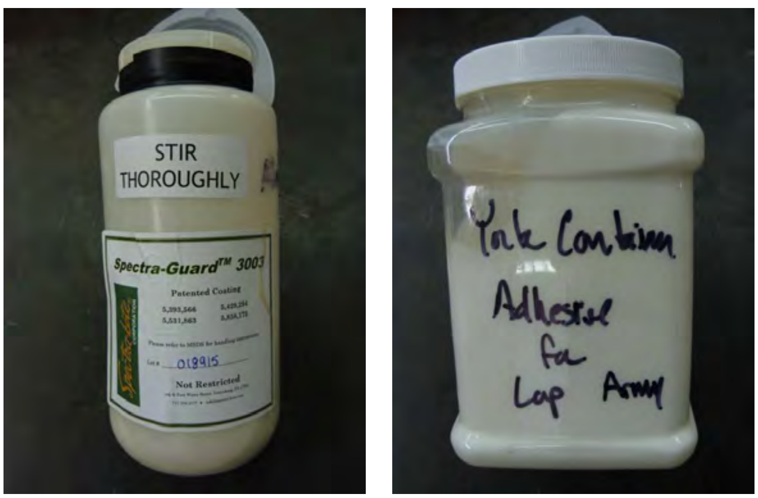
The water drop penetration of handsheets made from the recyclability test sample must not exceed the water drop penetration of the control handsheets by more than 200 seconds.

5.4 Biodegradability

Evaluate four (4) materials for mean bio-based content using ASTM D6866 as shown in Figure 24. Note in sample b that the top layer was removed so the corrugation and lap adhesives were not included in the analysis.

Figure 24. Samples for Biodegradation a) MRE current box, b) current liner, c) corrugated medium in new box (38 Norshield) d) liner (69 lb)

Evaluation according to the ASTM D6400 Mineralization of a Coating and Adhesive exposed for 180 days to Aerobic Composting (Biodegradation) using ASTM D5338 @ 58 ± 2°C through contact with compost medium was also completed. Compare the results to the biodegradation rate of a positive control of cellulose.



a) b)

Figure 25. a) Spectra-Kote Spectra-Guard 3003 Coating and b) York Container Lap Adhesive

5.5 Insect Infestation

Fiberboard pieces were tested before the full containers were tested. In total, there were 25 cases of current fiber board packaged MREs and 25 cases of corrugated packaged MREs. All 50 cases were tested for infestation resistance in a climate controlled building. Environmental testing conditions were 80 ± 5^{0}F and 65 ± 5% RH. Insect species used were the red flour beetle, cigarette beetle and Indian meal moth. Test duration was 12 weeks.

5.6 Aerial Delivery

NSRDEC requested that YTC conduct a customer test to assess an alternative packaging container for MRE rations when airdropped using high-velocity (HV) Container Delivery System (CDS) configuration.

YTC performed demonstration airdrops in HV CDS airdrop rigged configurations to assess the durability and survivability of the corrugated fiberboard containers well packaged with rations. The solid fiberboard weighs 1.71 lbs flat with outside measurements of: length 17 inches (in.), width 9.25 in., and height 10.62 in. The weight of a packed container with MREs was 21.05 lb. Figure 26 lists the measurements and shows how the MREs are packed inside the container.

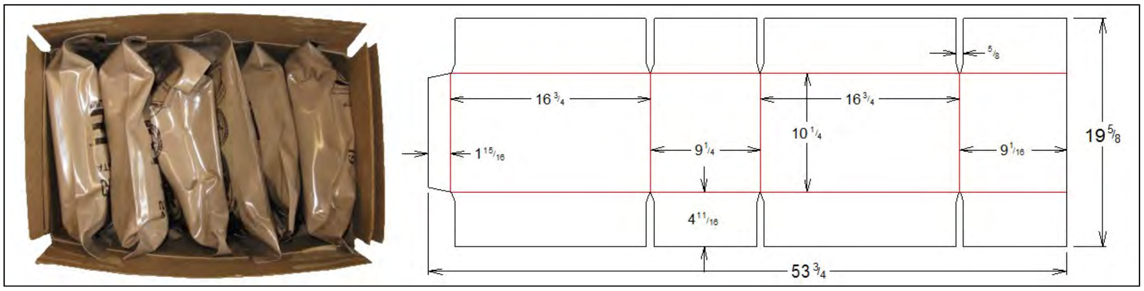


Figure 26. MRE Solid Fiberboard Container

The corrugated fiberboard weighs 1.33 lb. flat with outside measurements of: length 15.75 in., width 9.87 in., and height 9.75 in. The weight of a packed container with MREs was 20.80 lb.

The Primary Supporting Materiel was a contracted C–130A from TBM Incorporated.
The following equipment was used: 40K-loader (Load CDS), 6,000-lb forklift, Mobile crane (Recovery), Flatbed truck (Recovery), Testing Position: Robby Drop Zone (DZ) on the Cibola range, U.S. Army Yuma Proving Ground (YPG)

Facilities: Air Delivery Complex (Building 2970), Mission Control (Building 2105)

Instrumentation: MPS–25/TPQ–39 Radar, Hand-held anemometer, Hand-held Global Positioning System (GPS) receiver, Aircraft on-board video to capture first motion and ramp views, Stabilized Kinetic Tracking Mounts (KTMs) for ground-to-air video, Accelerometers capturing opening forces of selected airdrops (customer supplied), Ground-to-air still camera, Radio Wind (RAWIN) sounding from mobile meteorological (MET) unit, Surface Atmospheric Measurement System (SAMS)

Four airdrops, four with LV CDS parachute systems of the new MRE corrugated fiberboard container were performed.

Data collected during the test has been stored in the YTC Airdrop Database, which was a Microsoft Access-based relational database hosted on a secure YTC server and capable of producing one-page data sheet summaries for each airdrop. All data collected have been made available to NSRDEC. Additionally, documentation and multimedia have been posted to the Vision Digital Library System at https://vdls.atc.army.mil.

On 31 July 2015, YTC conducted a customer airdrop test to assess an alternative packaging container for MRE rations using an HV CDS configuration using an LV CDS configuration.

All the MREs were airdropped during four passes over Robby DZ from a C–130 aircraft. The first two passes were in LV CDS configuration from an altitude of 1,500 ft. AGL and the next two passes were in HV CDS configuration from 15,000 ft. MSL.

The examination of data collected by YTC personnel allowed NSRDEC personnel to make determinations on the survivability of the ration types involved. The data allowed NSRDEC to compile statistics on both success and failure rates of individual MRE rations and their components. YTC collected multimedia documentation, MET data, and additional airdrop data during the test program. Details of the data are as follows:

a. Multimedia Documentation in the form of DVDs:

(1) Ground-to-Air Video. Video data were provided to the NSRDEC using coverage obtained from three ground-based KTMs.

(2) Still Photography. Still photographs of the hardware during test preparation, execution, and post-test assessment were provided. Each payload was inspected for damage after each airdrop.

(3) On-board video to captured first motion and ramp views exits. The first motion camera captured the initial movements on the CDS payloads and the ramp camera provided a view of payloads facing aft towards the aircraft ramp providing a view exiting the aircraft and the initial parachute opening sequence.

b. MET Data

(1) RAWIN Sounding. A MET sensor attached to a helium weather balloon was released once before the airdrop. Measurements include altitude, temperature, density, and pressure. The data were collected in 100-foot (ft.) increments to at least 20,000 ft. mean sea level (MSL). YTC test personnel used this data to compute a surface danger zone prior to airdrop.

(2) Joint Air Force and Army Weather Information Network (JAAWIN). The JAAWIN (https://weather.afwa.af.mil) system provided weather information, which allowed the test officer (TO) to obtain detailed forecast weather in advance of the planned mission. The YTC TO used this data for pre-planning prior to airdrop.

(3) SAMS. Fixed-site SAMS stations are located throughout YPG. The SAMS stations record time-correlated wind speed and direction (15-minute average and peak), temperature, barometric pressure, and relative humidity at a height of 2 meters above ground level (AGL). The SAMS provided constant (15-minute interval) data that were monitored to view winds on or near the DZ up until the time of the airdrop.

(4) kHand-Held Anemometer. A hand-held anemometer was used by the YTC DZ Safety Officer to relay the wind speed and direction at the time of each airdrop to the YTC test technicians who recorded the ground winds for both the exit and impact of the loads.

c. Additional Data

(1) Airdrop exit and impact time of payloads (plus or minus [±] 1 second)

(2) Total system weights (±5 lb)

(3) Impact coordinates were recorded by the YTC TO with a hand-held GPS receiver device.

YTC executed four validation airdrops assessing solid fiberboard and corrugated fiberboard containers for payload survivability. Post drop, NSRDEC personnel with the support of YTC test personnel inspected all MRE payloads at Building 2970 at Yuma, by unpacking all MRE containers to determine if the MREs were in an "edible" condition by a visual inspection. YTC provided NSRDEC with digital photography data to support their assessment of MREs survivability. Table 11 shows the test matrix completed for the airdrops.

Table 11. MRE HV and LV CDS Test Matrix

Airdrop No*	CDS	Parachute	Altitude (ft)	MRE	Susp Wt (lb)	TRW (lb)	Remarks
2015–1071a	HV	26-ft RS	15,000 MSL	Regular	1,126	1,156	Corrugated MRE Container
2015–1071b	HV	26-ft RS	15,000 MSL	Regular	1,120	1,151	Corrugated MRE Container
2015–1072a	HV	26-ft RS	15,000 MSL	Regular	1,134	1,164	Solid MRE Container
2015–1072b	HV	26-ft RS	15,000 MSL	Regular	1,134	1,164	Solid MRE Container

*Note: All drop speeds were 130 KIAS

YTC personnel followed Field Manual 4–20.103 (Rigging Containers) to build the HV and LV CDS payloads along with the ATEC report 2013–CT–ABN–CTXXX–F7676 (HV Airdrop of Military Rations with Modified Energy Dissipation Material Configuration) as additional supporting rigging documentation.

Figure 27. HV Parachute System MREs

5.7 Distribution / Transportation

5.7.1 Brief Description: A new coated corrugated material for the cases of MREs was being evaluated via a transportation study against the current solid fiberboard shipping cases. For this study, 8 pallets of MREs, which were previously stored in Marengo Caves Warehouse for one year, are traveling to four military bases to experience several environments that can be expected throughout the life of an MRE container. The pallets were inspected at each of the four locations when they arrive, and once again after storage for two months.

Upon arrival at each location, each pallet of MREs were visually inspected without removing or opening the containers on the pallet. This was a visual inspection only and the stretch wrapping, strapping and unit caps were not be removed from the pallet. NSRDEC inspectors conducted a more invasive inspection at the end of the storage period at each location, but the initial inspection upon arrival of the containers at the storage location was visual only. This initial inspection helped determine any defects that arose during the transportation from one location to the next and not due to the storage of the containers at the location.

5.7.2 Inspection Task: Each pallet in the inspection has been numbered from 1-8. The current control solid fiberboard boxes are on pallet numbers 3,4,5,6 while the new corrugated containers are on pallets 1,2,7,8. **STEP 1:** All eight pallets were laid out on the floor unstacked with sufficient room to walk all of the way around each one. The pallets were labeled by numbers using black marker which was on the front and back side of the wooden pallet runners. Also labeled on the face of the wooden pallet runners was the letter “F”, which indicates the “front” side of that unit load. This labeling helped determine the correct box number for the inspection according to below. **STEP 2:** Using the provided Inspection Sheet, the inspectors walked around the outside of each pallet (as indicated in Figure 2) taking note of container defects which are listed on the sheet and pictured below. Listed were the corresponding letter for each defect in the “Defects” box on the inspection sheet for the overall pallet and each individual container. Also included were any observations which did not strictly follow the inspection sheet (and photos when possible). The pallet diagram shown in Figure 28 was used for correct numbering, as the cases themselves were not labeled. For defects which were listed under “Overall Pallet”, the defects needed to be noted once in the overall box, and again in the box locating its position. **STEP 3:** The height of each pallet was measured starting from the floor at the front near box number 12 to the closest 1/8 of an inch. **STEP 4:** It was ensured that pallets were stacked no more than four high following completion of the initial inspection for the remainder of the storage. It was also noted which pallet was on the bottom for this period.

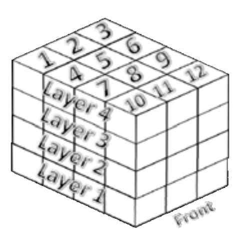


Figure 28. Container numbering system for visual inspection

5.7.3 Helpful notes from inspectors during initial inspection at the warehouse: The inspectors started with the top layer and worked around the pallet starting at the front (marked with an F on the wooden pallet runners) before continuing on to the next layer down. The inspectors were aware that it was possible for two sides of the same box to be visible on two sides of the pallet. The inspectors made sure to list all defects for the correct box. A modified Inspection Sheet was created to facilitate inspection following the arrows in the diagram shown in Figure 29. (This pattern follows in this order: 10 -> 11 -> 12 -> 9 -> 6 -> 3 -> 2 -> 1 -> 4 -> 7, then 10 again.) Boxes 5 and 8 were not visible while in the pallet configuration. It was ensured that the pallet load was not altered to get to these boxes as they were inspected by NSRDEC inspectors at the end of storage at each location. This was only used as a reference as the main inspection remarks were recorded using the inspection sheets provided. The letters identified in the "defects listed" column are defined below on the last few pages..

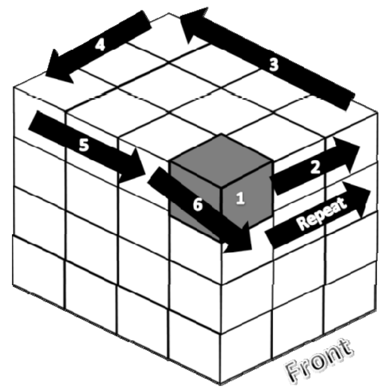


Figure 29: Suggested inspection procedure

Figure 30 shows the labeling of the pallet that was used in this transportation study.

Figure 30. Location of Labels for Front and Pallet Number

The locations and dates for the transportation study are shown below. Inspections were performed upon arrival and departure at the location.

Location #1:
Marengo Warehouse and Distribution Center
300 East Union Street, Marengo, IN 47140

Depart: 18 Nov 2014

Location #2:
Joint Base Elmendorf-Richardson
804 Warehouse Street AWCF SSF
JBER, AK 99505
Arrive: Week of 8-12 Dec 2014
Depart: Week of 9-13 Feb 2015

Location #3:
Joint Base Lewis-McChord
Yakima Training Center
Yakima, WA 98901
Arrive: Week of 23-27 Feb 2015
Depart: Week of 27-30 Apr 2015

Location #4:
Fort Bliss
Bldg 1109 Alleshire Road
Ft. Bliss TX 79916
Arrive: Week of 4-8 May 2015
Depart: Week of 6-10 July 2015

Location #5:
Fort Stewart
793 McFarland, Av, Building 11012
Ft. Stewart, GA 31314
Arrive: Week of 13-17 July 2015
Depart: Week of 7-11 Sep 2015

The objective was to evaluate the integrity and performance of a lightweight corrugated MRE shipping container through shipments to and from various military TISA locations in several different environments throughout the United States.

5.7.4 Concept of the Evaluation

A. The transportation evaluation tested the performance of a corrugated shipping container and the current solid fiber MRE shipping container during transportation, loading/off-loading operations, and storage at several military locations. At each location, the NSRDEC provided inspectors that will travel to the TISA and conduct full inspections of the containers and identify all damage found on each container.

B. Eight pallets (64 containers per pallet) of filled MRE shipping containers (4 corrugated and 4 solid fiber controls) were shipped from the Marengo Warehouse Center in Marengo, IN via ground/ferry transport to the first TISA in Alaska (December 2014). These pallets arrived strapped and stretch-wrapped in the same fashion as the current

C. MRE pallets are. At this location, each pallet of MREs were unloaded (still strapped and stretch-wrapped) via forklift and stored in the same location that was used to store MRE rations during every-day operations. These pallets were to be stored 1 pallet high, without any stacking of pallets. These pallets remained in storage for approximately 8 weeks without tampering. After 8 weeks of storage, NSRDEC inspectors broke-down two pallets of containers (1 Corrugated and 1 Solid Fiber Control) and conducted a 100% inspection of the containers on the pallet and the MRE packaging to validate the condition of the containers and determine locations and extent of any damage. After the NSRDEC inspectors completed the inspection on the two test pallets, the MREs were left at the TISA and undamaged MREs were disposed of or consumed at the direction of the TISA. The remaining pallets of MREs that were not inspected were then shipped along to the next TISA location where the same procedure occurred. This process continued at each TISA location until the last pallets of MREs were inspected. An illustration of this demonstration is shown in Figure 31 below with each pallet of containers numbered and color-coded (Solid Fiber-Red, Corrugated-Green). All test pallets were color marked on the wood pallet and letter/number coded by side so that they could be distinguished amongst all the pallets of rations in storage at the test location and so that damage could be identified and recorded based on location in the pallet load.

D. The loading/unloading operations of the MRE pallets was done in a similar manner as is done under everyday conditions. The purpose of the test was to evaluate the containers performance, therefore special handling of these cases was not conducted in order to get a true performance evaluation. Each pallet was handled as any other MRE pallet would be under normal working conditions.

E. .

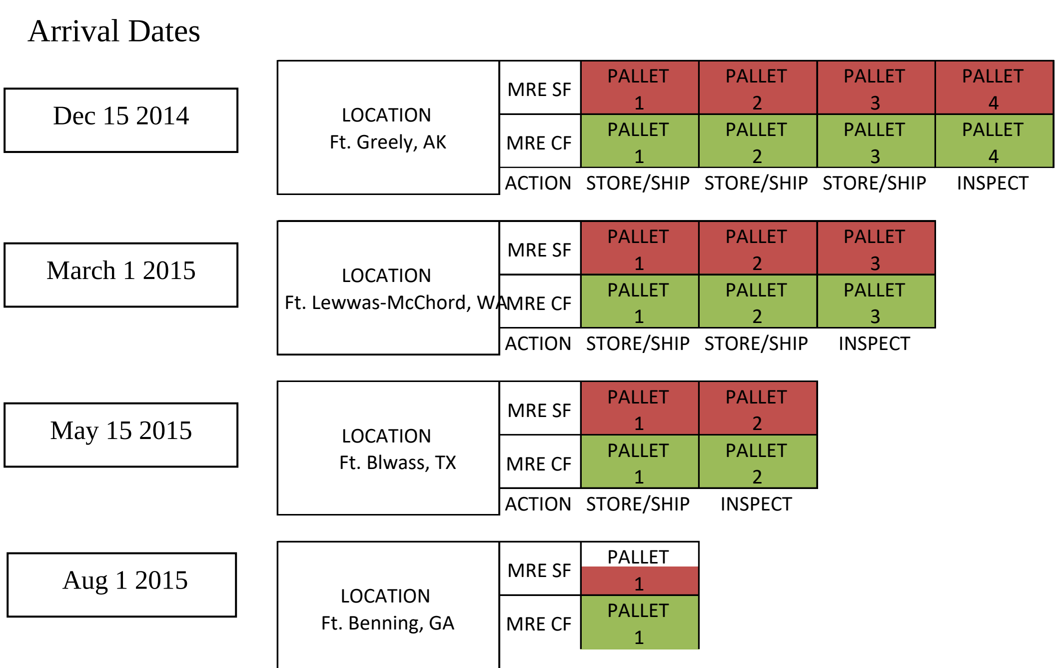


Figure 31. Illustration of Transportation Demonstration for MRE Containers Showing Solid-Fiber Containers (Red) and Corrugated Containers (Green)

5.7.5 Requirements for the Support Units:

A. Type of unit: TISA MRE Material Handlers at each of the 4 test locations that was typically assigned to handle incoming shipments of ration items (MRE, UGR, etc.) as well as outbound shipments.

B. Number and size of units: As-needed for typical handling of 2-8 pallets of MRE containers

C. Length of evaluation: 1 day of unloading followed by 8 weeks of storage at each location. Total evaluation time, including transportation between locations, was estimated at 10 months.

D. Environment: Seeking cold and wet environments in first two locations followed by hot/dry conditions at the third location and hot/humid conditions at the fourth and final location.

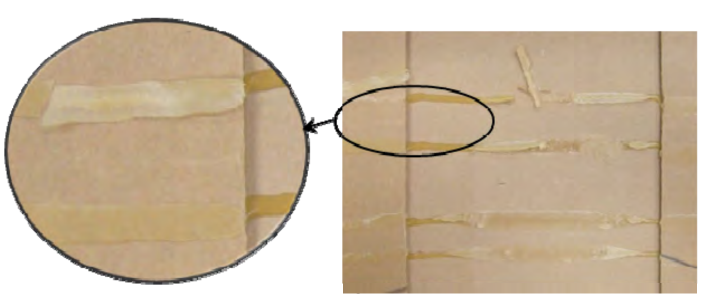
E. Time Frame: Between 15 Dec 2014 and 15 October 2015

Command brief was requested only as needed to instruct TISA material handlers as to the procedure requested to carry out this test and evaluation. If civilian material handlers were used at the TISA to unload, store, and ship pallets from one TISA location to the next, no soldiers would be needed for this test and evaluation exercise. Table 12 depicts the defects and pallet that was filled in at inspection.

Table 12. Pallet Information and Defects

Pallet Number New/Legacy		Height	Defects Listed	Defects Count	Boxes w/ Defects Count
Corrugated Fiberboard Boxes					
1	1	42 1/8”			
2	2	42 1/2”			
3	7	42 1/4”			
4	8	42 1/2”			
Solid Fiberboard Boxes					
1	5	41 ½”		5	5
2	6	41 ½”		6	6
3	3	41 ½”		4	4
4	4	41 ½”		7	7

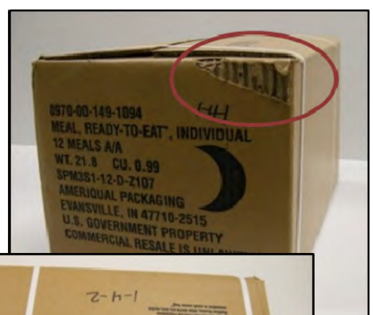
5.7.6 Pictures and Descriptions. The pictures and descriptions below represent the defects or failures that could be observed during inspection.



A. Adhesive Failure; -Failure Mode 1: No Fiberboard Damage, Failure Mode 2: Flap came loose. Note: Only be seen in Full Inspection of pallet.

B. Bottom Crush Stress creasing on bottom face of box, or creasing seen near the bottom edge.

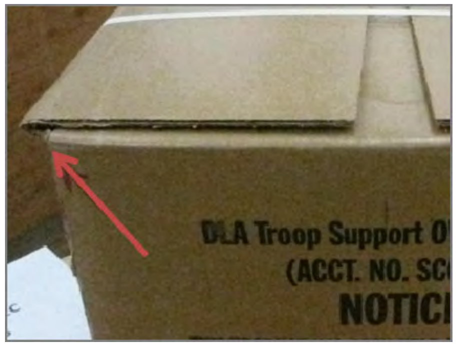
C. Corner/Edge Crush Crushing, creasing, folding or bending of the fiberboard near a corner or on the vertical edges. Indicate which one was found in the Observations.



D. Separation of Fiberboard Layers Delamination or Peeling. Inner layers are visible.

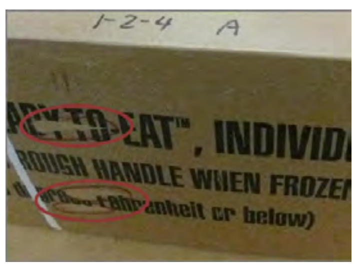
E. Excessive Gap Width Greater than ¾ of an inch. May indicate loose flaps or adhesive failure.

Note: Only be seen in full inspection of pallet.



F. Flaps Pushed Out Flap does not conform to corner of the box. Most likely also result in excessive gap width.

G. Puncture Hole in box. Any time internal packaging was visible. Any small or large dent in packaging, localized in a circular shape.



H. MRE(s) Damaged: If any MRE components were found to be damaged, the inspectors put a "Y" in the box on the inspection sheet and indicate the meal number and component(s). Note: This would only be observed during full pallet inspection. **I. Superficial Damage** -Failure mode 1: Faded/Running/Smudged Ink -Failure Mode 2: Rip/tear/abrasion

Any damage which causes the labeling to be partially or totally illegible. Structural integrity left unchanged.

Below was a sample inspection sheet.

ESTCP Fiberboard MRE Box/Pallet Inspection Sheet

Inspector:_________________________ **Location:**________________________ **Date:**___________

Check one : **Arrival**___ **Departure**___

Defects:

Individual Box		*Pallet Overall*
A. Adhesive Failure	E. Excessive Gap Width	I. Superficial Damage
1. No paper ripping observed.	F. Flaps Pushed Out	1. Ink Fade/Run/Smudg
2. Flap is loose.	G. Puncture Damage	2. Rip/Tear/Abrasion
B. Bottom Crush	H. MRE(s) Damaged.	J. Stretch Wrap Loose/Rippe
C. Corner/Edge Crush	1. Check "MRE damage" box.	L. Load Shift While Palletize
D. Delamination of Paper Layers	2. Indicate component(s).	O. Other

*Mark defect codes in box marked "***Defects:***" Describe defect in Observations.*

Pallet #	**SF/CF**	**Overall Pallet Defects:**		**Deformation**
			Height:	

Pallet Observations:

#	Layer	Box	Defects:	MRE Damage *(Check Y)*	Observations:
1	4	1			
2	4	2			
3	4	3			
4	4	4			
5	4	5			
6	4	6			
7	4	7			
8	4	8			
9	4	9			
10	4	10			
11	4	11			
12	4	12			
13	3	1			
14	3	2			
15	3	3			
16	3	4			
17	3	5			
18	3	6			
19	3	7			
20	3	8			
21	3	9			
22	3	10			
23	3	11			
24	3	12			

#	Layer	Box	Defects:	MRE Damage *(Check Y)*	Observations:
25	2	1			
26	2	2			
27	2	3			
28	2	4			
29	2	5			
30	2	6			
31	2	7			
32	2	8			
33	2	9			
34	2	10			
35	2	11			
36	2	12			
37	1	1			
38	1	2			
39	1	3			
40	1	4			

5.8 Waste-to-energy

5.8.1 Background The overall objective of this program was to evaluate the fiberboard in the BWEC that was already being utilized by the Army for studies. This was a program to provide the NSRDEC with a BWEC system suitable for use at contingency base camps. This program was conducted to address a myriad of health, security, and economic challenges associated with waste management and fossil fuel supply in deployment scenarios, many of which are intensified for smaller base camps. The BWEC system takes mixed solid waste generated from these basecamps and, through a downdraft gasification process, converts it to a high energy content syngas which can then be used to fuel a modified diesel generator. Instead of going to an incineration operation or landfill, the BWEC system processes the waste and converts it to usable electricity, thereby reducing the installation's dependence on fossil fuels to operate generators.

Infoscitex Corporation (IST) collaborated with MSW Power Corporation to convert their GEM waste-to-energy technology as a baseline system from which a containerized solution could be developed to meet the US Army's Battalion-scale Waste-to-Energy Conversion requirements. The GEM System was developed by MSW Power personnel under previous contracting efforts with the DoD in a single, large shipping container for use at stationary sites. The principal difference of the BWEC system was mobility. The BWEC system took the functional elements of the GEM and broke them into three 20-ft. ISO containers to support rapid deployment, packing and air logistical transport standards. The final design schematic and photograph of the as-tested system can be found in Figure 32 and Figure 33, respectively. Details of the BWEC system are given below:

- A compact loading system utilizes distributed carts around the base to collect the waste. The carts are loaded into the front-end loader providing up 2-3 hours of waste storage. The carts are fed one at time to a vertical lift system that dumps the cart contents into the SWP system.
- A versatile solid waste preprocessing unit capable of converting a range of waste streams (refuse derived fuel and biomass, such as wood), into waste-based fuel pellets of ideal size, density, and moisture content for gasification. The solid waste was shredded, dried and densified into pellets for use in a downdraft gasifier. Densified fuel pellets are much more desirable than unconsolidated shredded waste because they facilitate transport and feeding of the waste feedstock and permit more optimal and higher efficiency gasifier operation through control of the height of the gasification zone and air flow in the gasifier; the denser the fuel pellets, the more uniformly they burn in the gasifier.
- The electricity required to run the preprocessing unit and the heat required to dry the shredded waste to produce high quality pellets are supplied by the generator system. During start up, diesel fuel was used to create the electricity to process the waste. The unit has a parasitic energy loss (the energy required for preprocessing the unconsolidated solid waste into pellets) of less than 5% of the energy in the pellets.
- A clean-burning gasification unit capable of generating a low tar, low particulate producer gas of composition suited to produce on-site electricity from a modified diesel generator.
- The diesel generator was designed to operate on diesel (or JP-8) and was modified to accept producer gas from the BWEC gasifier and has a rated capacity of 115 kW_e. Based on the waste composition, the BWEC system was expected to provide a total of 90 kW_e on demand and 65 kW_e net.

- The BWEC demonstration system was capable of recovering >150 kW_T of waste heat for drying the shredded waste.
- An integrated control system to allow 24/7 and weather independent operation with minimal manpower supervision.

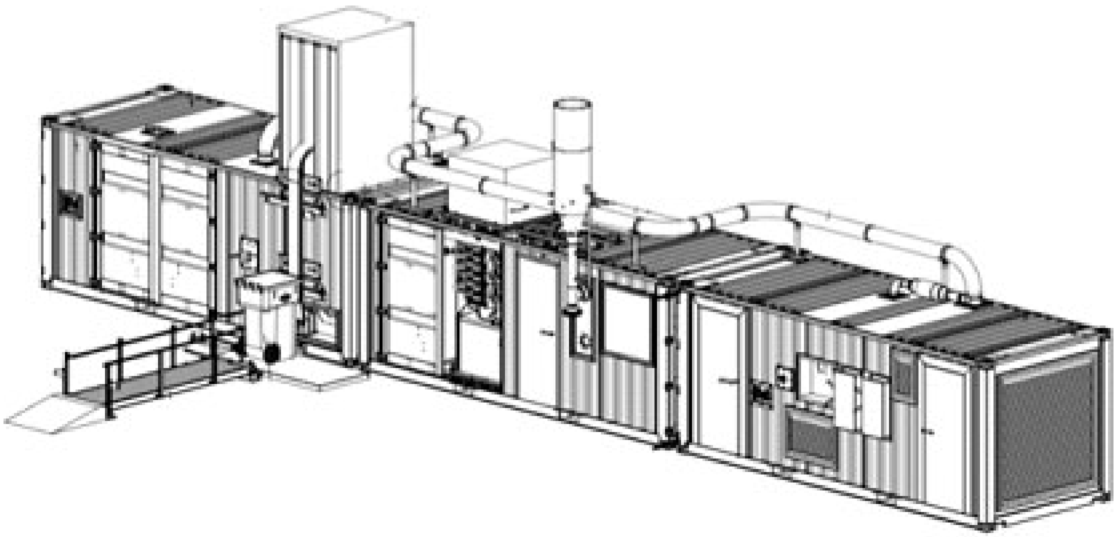


Figure 32. Full BWEC system design in the demonstration configuration (with optional cart feeder system)

Figure 33: Photograph of the BWEC system during demonstration at Ft. Benning

A full week starting was required to adequately prepare for and conduct the desired study. Overall, the Fiberboard demonstration followed the anticipated schedule. The only significant difference was the timing and order of the feedstock pelletizing. There were several delays delivering the control fiberboard involving the freight company. The control fiberboard feedstock did not arrive until lunchtime on day 2 (12/6/16). To avoid delays, we processed the trial feedstock on Day 2 and the control fiberboard feedstock on Day 3. In both the trial and control fiberboard cases, the palletization process needed to be modified, which resulted in longer processing times. The final as-executed schedule was as follows:

- Day 1, 12/5/16: Travel, Trial feedstock procurement and feedstock preparation
- Day 2, 12/6/16: Trial fiberboard preparation and pelletization, control fiberboard delivery
- Day 3, 12/7/16:
  - Trial fiberboard pelletization
  - Control fiberboard preparation
  - Trial fiberboard pellet processing in the BWEC system
- Day 4, 12/8/16:
  - Control fiberboard preparation and pelletization
  - Control fiberboard pellet processing in the BWEC system
- Day 5, 12/9/16: Site cleanup and travel

5.8.2 Feedstock Preparation

IST recommended that a standard waste composition (paper/cardboard, food, plastic, overall moisture content) be defined for comparison between conversion of waste featuring traditional fiberboard and waste featuring the trial fiberboard. Photos of the feedstock pallets can be seen in Figure 34. The following feedstock recipe Table 13 was developed for anticipated ease of pellet formation and high fiberboard content:

Table 13. Fiberboard feedstock recipes

63% Fiberboard

Supplied by NSRDEC

Control and experimental types

30% Food

25% dry dog food

3% vegetable oil

72% water

7% plastic

- Blend of polypropylene and polyethylene feedstock
-

Figure 34: Trial corrugated cardboard/fiberboard on left, control fiberboard on right

5.8.3 Schedule

IST recommended that a standard waste composition (paper/cardboard, food, plastic, overall moisture content) be defined such that an apples-to-apples comparison can be made between conversion of waste featuring traditional fiberboard and waste featuring the new fiberboard. During feedstock preparation activities the team made ten 120-lb mixtures of the recipe in 95-gallon recycling carts according to the following procedure:

1) Premix 36 lbs of food ingredients in 5-gallon buckets with water to ensure adequate absorption
2) Tare weigh recycling cart
3) Add 75.6 lbs of cut fiberboard to recycling cart
4) Add 8.4 lbs of plastic (plastic grate shelving stock) to recycling cart
5) Add 36 lbs of food mix as other constituents are added to cart to ensure good mixing
6) Weigh final mass of recycling cart

During the feedstock preparation period, a small amount was set aside to confirm that the recipe was generating good pellets. Those pellets were saved for use during the operational phase of the effort.

The following process was used first with the control fiberboard and then with the experimental fiberboard.

Once the feedstock was ready, it was pelletized in the solid waste preprocessing unit of the BWEC system. Approximately 1,200 lbs of feedstock was used to create about 1,000 lbs of pellets. A sampling of these pellets was set aside for analysis.

The pellets were then be fed to the reactor unit for gasification and use as syngas to run the generator unit. Power from the generator was fed to the Ft. Benning power grid. It was anticipated that between 750 and all 1,000 lbs of pellets was used to run the reactor for six hours. This was long enough to ensure all previous waste pellets and char has moved through the system and the system had enough time to stabilize on the fiberboard feedstock. Towards the end of the run, producer gas and emissions sampling occurred. All electricity generation data was logged for the complete run.

The following analyses was conducted after the test:

- **Pellet properties**. Determine if the new fiberboard has any impact on the ability to form mixed waste pellets of acceptable integrity. Pellets were produced using the BWEC SWP and were assessed for mechanical performance, appearance, and suitability for processing.
- **Solid waste discharge.** Determine if the new fiberboard has any impact on the conversion efficiency (mass %) of the system. In addition to ash discharge

mass, analysis was performed to determine whether the ash meets standards for non- hazardous discharge (Heavy metal analysis was performed by Pace Analytical Labs).

- **Ambient air quality impact.** It was determined that the new fiberboard does not have any impact on the emissions profile of the diesel genset tasked with converting producer gas into electricity. A Testo 335 emissions tester was used to perform onsite sampling of the genset exhaust.
- **Producer gas quality.** It was determined that the new fiberboard does not have any impact on producer gas quality. Gas composition and energy content of the producer gas was assessed by Pace Analytical Labs).

During feedstock preparation activities variations on the recipes were incorporated to improve pellet quality. The decision was made to modify the recipes for the two types of feedstock in order to get viable pellets with the smallest recipe modifications possible. The recipes can be found in Table 12.

5.8.4 Operations

A total of 342 lbs of trial feedstock was processed. The pellet runs varied in quality but a typical fines percentage was 9-10%. A total of 315 lbs of pellets were produced and after filtering the fines 309 lbs trial pellets were fed to the reactor.

A total of 429 lbs of control feedstock was processed. The fines percentage using control recipe #1 was 27%, hence the change to control recipe #2. Using control recipe #2, the fines were slightly reduced to 24%. A total of 328 lbs of control feedstock pellets were fed to the reactor. At the end of the control feedstock run, the waste-generated pellets left over from 12/5/16 were added to the reactor to extend the run.

5.9 Emissions

5.9.1 EPA Objectives

The objectives of this work were to determine and compare air emissions from open burning of:

- Current and newly-developed MRE fiberboard packaging options; and
- Current MRE aluminum-based pouches and newly-developed nanocomposite-based pouches.

Emissions that were characterized included health-related compounds: $PM_{2.5}$ and PM_{10} (particulate matter with aerodynamic diameter equal to and less than 2.5 µm in diameter and particulate matter with aerodynamic diameter equal to and less than 10 µm in diameter), elements/metals in PM, polychlorinated dib Enzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs), polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO), carbon dioxide (CO_2), and volatile organic compounds (VOCs). $PM_{2.5}$ was a criteria pollutant regulated by the U.S. EPA since these particles can enter the lungs when inhaled and potentially carry metals and other toxic pollutants, which can cause adverse health effects. PCDDs/PCDFs are persistent in the environment and are of interest due to their health effects including immunotoxicity, carcinogenicity, and teratogenicity. Many VOCs are on the U.S. EPA's list of hazardous air pollutants with properties that are toxic and carcinogenic for humans. Some PAHs are classified as possible human carcinogens.

Materials and Methods

Seven fiberboard materials were studied for their emissions when combusted in an open burn scenario:

- Current solid fiberboard box (CB);
- Current solid fiberboard liner (CL);
- New corrugated fiberboard box with Spectra-Kote polymer (SB) (Spectra-Kote Corp., Gettysburg, PA, USA);
- New corrugated fiberboard liner with Spectra-Kote polymer (SL);
- New fiberboard box with no Spectra-Kote polymer (NSB);
- New fiberboard liner with no Spectra-Kote polymer (NSL); and
- Current solid fiberboard box without wet strength (NWS) polymer.

Analyses of these materials (Galbraith Laboratories, Inc., Knoxville, TN, USA) are reported. Differences in the Spectra-Kote boxes/liners are noted, particularly for loss on drying, chlorine, and sulfur.

Table 14. Ultimate proximate analysis for the seven fiberboard materials.

	Current Fiberboard Solid Box	Current Fiberboard Liner	Corrugated Spectra-Kote Polymer Fiberboard Box	Corrugated Spectra-Kote Polymer Fiberboard Liner	No Spectra-Kote Box	No Spectra-Kote Liner	Current Fiberboard Box - No Wet Strength
Code	**CB**	**CL**	**SB**	**SL**	**NSB**	**NSL**	**NWS**
Heat of combustion (BTU*/lb)[1]	8121	7955	7537	7166	7598	7979	8145
Loss on drying (%)[2]	7.45	7.49	9.45	9.13	9.48	8.51	10.24
Carbon (%)[3]	46.3	46.19	44.99	45.44	45.36	45.85	46.56
Chlorine (ppm)[4]	188	185	297	251	97	57	139
Hydrogen (%)[5]	6.08	6.16	6.13	6.02	6.29	6.20	6.03
Nitrogen (%)[6]	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sulfur (%)[7]	0.234	0.243	0.162	0.155	0.149	0.140	0.236

*British thermal unit(s). Galbraith procedures: [1]S-231; [2]S-200; [3]ME-14; [4]ME-4A; [5]ME-14; [6]ME-14; [7]E16-2.

Table 15. Carbon fraction of each waste material and category. [A]

Waste Material	Carbon Fraction in Material	0 % NEW	32 % NEW	66 % NEW	100 % NEW
		Carbon fraction from each waste category[b]			
Old material	0.37	4.2E-02	2.1E-02	1.3E-02	NA
New Material	0.74	NA	2.7E-02	5.2E-02	8.2E-02
Plastic	0.74[c]	1.3E-01	1.3E-01	1.2E-01	1.3E-01
Cardboard	0.46	1.4E-01	1.4E-01	1.3E-01	1.4E-01
Paper	0.44[c]	7.0E-03	7.1E-03	6.6E-03	7.0E-03
Al-bag	0.0076[c]	1.3E-04	1.3E-04	5.0E-04	1.3E-04
Matches	0.50	4.9E-03	5.0E-03	4.7E-03	4.9E-03
Adsorbent package	0.0076[c]	3.6E-05	3.7E-05	3.4E-05	3.6E-05
Food waste: Penne pasta	0.092	1.5E-02	1.5E-02	1.4E-02	1.5E-02
Beef stick	0.28	7.7E-03	7.8E-03	7.3E-03	7.7E-03
Toaster pastry	0.43	1.8E-02	1.8E-02	1.7E-02	1.8E-02
Crackers	0.51	1.4E-02	1.4E-02	1.3E-02	1.4E-02
Pretzels	0.39	1.0E-02	1.1E-02	9.9E-03	1.0E-02
Cappuccino	0.45	9.4E-03	9.6E-03	8.9E-03	9.4E-03
Salt	0.0076	4.9E-05	5.0E-05	4.7E-05	4.9E-05
Seasoning	0.49	1.3E-03	1.3E-03	1.2E-03	1.3E-03
Iced tea	0.49	2.4E-02	2.5E-02	2.3E-02	2.4E-02
Chewing gum	0.49	4.0E-03	4.1E-03	3.8E-03	4.0E-03
Total	**NA**	**0.42**	**0.44**	**0.43**	**0.46**

[a] Each waste category comprised of different percentages of new nanocomposite and old aluminum-based material, e.g., 32 % NEW = 32 % new nanocomposite material and 68 % old Al-based material of the total waste. [b] Data from Liu and Lipták [3]. [c] Carbon fraction in material × waste fraction in recipe.

Open Burn Test Facility

This work was conducted in the U.S. EPA's Open Burning Testing Facility (OBTF) located at EPA's Research Triangle Park, NC, campus constructed with Sheetrock® wallboard that was covered with stainless steel for ease of cleaning. High volume air handlers provide dilution air into the test facility to help ensure that open burn conditions (minimal depletion of oxygen concentration) are maintained within the facility during the tests. Measurements of the emissions exiting from the enclosed facility, together with the dilution rate of incoming combustion air, allow for calculation of emission factors in terms of pollutant mass per mass of material burned. The facility flowrate results in approximately one air volume change every 90 sec. The dilution air and combustion emissions exit the test facility through an 8-inch diameter (20.3 cm) transfer duct.

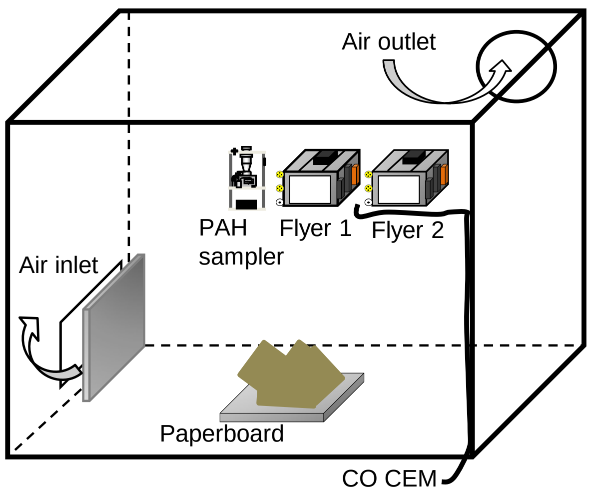


Figure 35. Schematic of open burn test facility. Not to scale.

The fiberboard/MRE sample was placed randomly on aluminum foil atop a sand-filled 3.2 × 3.2 foot (1 m × 1 m) steel plate. The average fiberboard weight for each burn was 4.7 lb (2.1 kg), 5.6 lb. (2.6 kg), 5.5 lb. (2.5 kg), respectively. Six MRE bags and half of a CB/CL fiberboard box was used for each MRE burn (based on 12 MRE bags in one fiberboard box); only 25 % of the food was included, simulating food not eaten.

Each burn was started with the use of a propane torch. Semivolatile organic compounds (SVOCs) and particulate matter (PM) collection started at ignition while Volatile Organic Compound (VOC) (SUMMA canister) sampling was started with a trigger when the CO_2 concentration had reached 800 ppm (this delay avoided the SUMMA canister opening prematurely during the ignition while the operator was still within the OBTF). VOC sampling was stopped when the CO_2 concentration diminished to 800 ppm. The SVOC and PM collection were stopped when the CO_2 concentration had reached the background concentration of approximately 400-500 ppm CO_2.

Figure 36. The paperboard test material (corrugated Spectra-Kote Polymer Fiberboard box and liner) atop aluminum foil (left) on 1 m x 1 m (3.2 ft × 3.2 ft.) steel pan. Combustion of same (right).

Figure 37. MRE (100 % OLD material or 0 % NEW) on 3.2 × 3.2 foot steel pan, before (left) and after (right) burn.

5.9.3 Test Matrix

The fiberboard tests and the MRE tests were conducted at separate times, November 2014 and July 2015, respectively. The tests were performed in random order (Table 16).To receive detectable levels of PCDD/PCDF, two to six separate burns had to be composited into one sample (one test). Table 16 shows the number of collected samples for each fiberboard and MRE category. A background sample was collected for each of the two test periods.

Table 16. Fiberboard test matrix.[a]

Fiberboard Type	Code	Test order	No. of Tests	Ash Samples
NA- OBTF Blank	BS	Pre-Test	1	NA
Current Fiberboard Container and Current Fiberboard Liner	CB/CL	3, 5, 7, 8	4	1 (composite)
New Polymer Coated Fiberboard Container and New Polymer Coated Fiberboard Liner	SB/SL	6, 9, 10, 11	4	1 (composite)
New Non-Polymer Fiberboard Container and New Non-Polymer Fiberboard Liner	NSB/NSL	4, 14, 15, 16	4	1 (composite)
Current Fiberboard, No Wet Strength	NWS	1, 2, 12, 13	4	1
NA - OBTF Blank	BS	Post-Test	1	NA

[a] NA – not applicable.

5.9.4 Emission Sampling System

Emission sampling was conducted using the "Flyer", which was a remotely controlled sampling system. This sampling was described more fully elsewhere [4; 5]. The Flyer includes an on-board computer, control software, and wireless transmitters which allow sampling to be monitored and controlled from a distance. Sampling periods are controlled using "triggers" and software to operate multiple on/off valves. Interchangeable sampling instruments allow for continuous CO_2, CO, temperature, and PM measurements as well as batch sampling of VOCs, SVOCs, PM_{10} and $PM_{2.5}$. The on-board computer and wireless data transfer also allow the operator to monitor CO_2 concentration, battery life, and pressure drop across a filter in real time. All sensor data and flow rates are logged to the on-board computer. A smaller version of the flyer was used to sample PAHs. To quantify the designated target analytes, the Flyer was comprised of the instruments indicated in Figure 38.

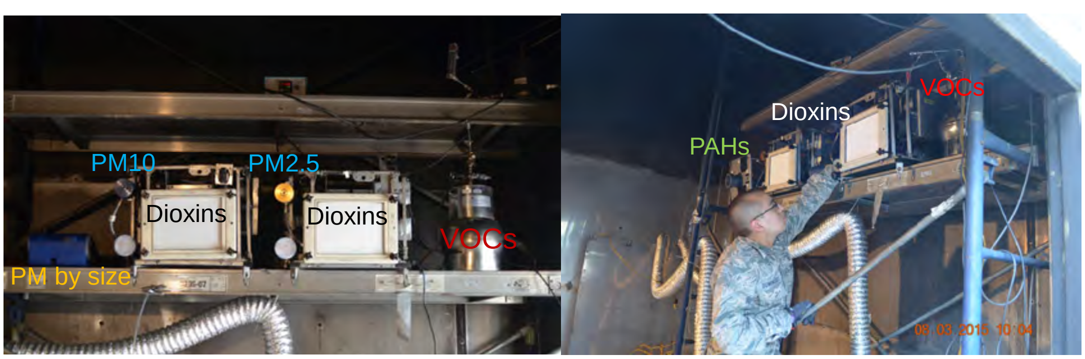


Figure 38. Flyer sampling instruments.

Table 17. Flyer emission sampling.

Pollutant	Instrument/Method(s)	Duration	Analytical Laboratory
$PM_{2.5}$ and PM_{10}	SKC impactors, 47 mm Teflon filters, PM by mass	Batch	Chester LabNet
PCDD/PCDF, PAH	Modified U.S. EPA Method TO-9A [6], U.S. EPA Method 23 [7]/HRGC-HRMS, U.S. EPA Method 8270D [8]/HRGC-LRMS	Batch	EPA/ORD
VOCs	SUMMA Canister/U.S. EPA Method TO-15 [9], including CO_2, CO, CH_4/U.S. EPA Method 25C [10]	Integrated run, 12 min samples	ALS Simi Valley
Metals	Teflon filters/gravimetric and X-ray fluorescence (XRF) [11]	Batch	Chester LabNet
PM mass and size	DustTrak DRX (PM_1, $PM_{2.5}$, PM_4, PM_{10} and Total PM)	Continuous	EPA/ORD
CO_2	LI-COR 820, Non-dispersive Infrared (NDIR)	Continuous	EPA/ORD
CO	Electrochemical cell, e2V EC4-500-CO	Continuous	EPA/ORD

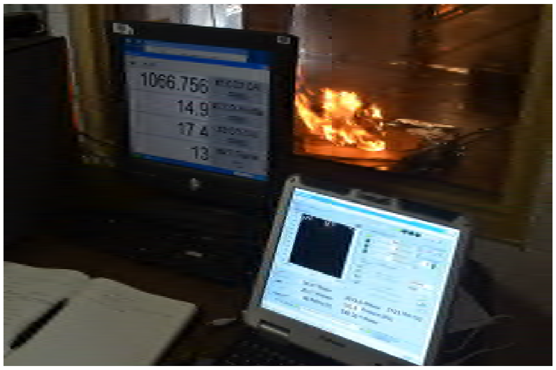


Figure 39. Monitoring of CEMs, SVOC flow rate, temperature, and SUMMA canister pressure during a burn.

5.9.5 Emission Sampling and Analytical Methods

5.9.5.1 SVOCs

PCDDs/PCDFs and PAHs were sampled using a low voltage Windjammer and MINIjammer brushless direct current blower. The blowers were started via wireless control at the start of the burn. The flow rate was measured by a 0-622 Pa pressure differential Setra Model 265 transducer across Herschel Standard Venturi tubes. The Venturi tubes were designed at EPA to meet the desired sampling rate for the target compound. The Venturi tubes were mounted on the outlet of the Windjammer and MINI jammer blowers. The voltage equivalent to this pressure differential was recorded on the onboard PC using the FlyerDAQ program or ARDUINO-based computer, which was calibrated with a Roots meter Model 5M, Dresser Measurement, Addison, TX, USA. in the U.S. EPA Metrology Laboratory before sampling effort. A temperature thermistor was used to measure the air temperature exiting the Venturi. PCDD/PCDFPCDDs/PCDFs were sampled via modified U.S. EPA Method TO-9A [6] using a polyurethane foam (PUF) sorbent preceded by a quartz microfibermicrofiber filter (20.3 × 25.4 cm) with a nominal sampling rate of 0.85 m^3/min (Windjammer). PAHs were also sampled via modified U.S. EPA Method TO-9A using a PUF/XAD-2 (polymer resin from Supelco Inc.)/PUF sorbent behind a quartz microfibermicrofiber filter (70 mm in diameter) with a nominal sampling rate of 0.18 m^3/min (MINIjammer). The PUF from Tisch Scientific, North Bend, OH was cleaned before use by solvent extraction with dichloromethane and dried with flowing helium to minimize contamination of the media with the target analytes and remove unreacted monomer from the sorbent. The PUF and PUF/XAD/PUF sorbents were mounted in a glass cartridges (Fischer Scientific) and inserted in a cartridge holder mounted on the Windjammer and MINIjammer blowers. The samples was extracted and cleaned up according to U.S. EPA Method 23 and analyzed using high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS). Blanks were collected and analyzed. Internal standards (Cambridge Isotope Laboratories, Tewksbury, MA, USA) were added to the sorbent before the sample was collected. The surrogate recoveries were measured relative to the internal standards and are a measure of the PUF/XAD/PUF/filter collection efficiency. A deuterated recovery standard, D10-pyrene, was added before mass analysis. Samples were analyzed on a Thermo Trace1310/ISQ GC/MS (Thermo Electron North America LLC, West Palm Beach, FL, USA) utilizing full-scan mode. All surrogate standard recoveries were between 48 and 110 percent, which was within the standard method criteria (25 and 130 %).

5.9.5.2 VOCs

Volatile organic compounds were sampled via U.S. EPA Method TO-15. Sampling for VOCs was accomplished using laboratory-supplied 6-L SUMMA canisters (ALS, Simi Valley, CA, USA). Each SUMMA canister was equipped with a manual valve, metal filter (frit), pressure gauge, pressure transducer, and an electronic solenoid valve. Pre-sampling tests showed canister fill times of 12 min.

The SUMMA valves were checked for leakage before sample collection by ensuring that the pressure gauge was not showing decreased vacuum with time. The SUMMA had its electronic solenoid valve controlled by the Flyer data acquisition (FlyerDAQ) program. The pressure transducer and electronic solenoid valve were connected to the Flyer, and the manual valve was opened. The electronic solenoid valve sampling system was opened and closed based on CO_2 concentration set points using the FlyerDAQ program. When the LI-820 measures elevated levels of CO_2, the Flyer DAQ enables the solid state relay, opening the SUMMA's solenoid valve to start sampling at the chosen frit filter sampling rate. The pressure transducer provided information on the status of the SUMMA (i.e., empty, filling, or full) to the FlyerDAQ interface. Following the end of sampling, the manual valve was closed, the SUMMA dismounted from the Flyer, the solenoid valve removed, and the canister was returned to its shipping container. SUMMA canisters were shipped to and from the field in boxes as per (ALS Environmental) instructions.

The VOCs were analyzed by ALS Laboratories (Simi Valley, CA) using U.S. EPA Method TO-15 [9] using full scan mode gas chromatography-low resolution mass spectrometry (GC/LRMS). The SUMMA canisters were also analyzed for CO_2, CO, and CH_4 by a GC/ flame ionization detector (FID) according to modified U.S. EPA Method 25C [10] by ALS Laboratories (Simi Valley, CA).

5.9.5.3 PM

5.9.5.3.1 PM batch sampling

$PM_{2.5}$ and PM_{10} were sampled with SKC impactors using 47 mm tared Teflon filters with a pore size of 2.0 µm via a Leland Legacy sample pump (SKC Inc., Pittsburgh, PA, USA) with a constant airflow of 10 L/min. PM was measured gravimetrically following the procedures described in 40 CFR Part 50 [13]. Particles larger than 10 µm in the PM_{10} impactor (or larger than 2.5 µm in the $PM_{2.5}$ impactor) were collected on an oiled 37 mm impaction disc. The Leland Legacy Sample pump was calibrated with a Gilibrator Air Flow Calibration System (Sensidyne LP, St. Petersburg, PA, USA).

5.0.5.3.2 PM Continuous Sampling

The TSI DustTrak DRX Model 8533 (TSI, Inc., Knoxville, TN, USA) was used to measure time-resolved particle size distributions. The DustTrak DRX measures light scattering by aerosols as they intercept a laser diode and has the capability of simultaneous real time measurement (every second) of PM_1, $PM_{2.5}$, Respirable (PM_4), PM_{10} and Total PM (up to 15 µm). The aerosol concentration range for the DustTrak DRX was 0.001-150 mg/m^3 with a resolution of ±0.1% of the reading. The flow accuracy was ±5 % of internal flow as controlled. The DustTrak DRX was factory-calibrated yearly to the respirable fraction (PM_4), with a photometric calibration factor (PCF) value of 1.00. A custom PCF was conducted as per manufacturer's recommendations for $PM_{2.5}$ and PM_{10} using the simultaneously sampled $PM_{2.5}$ and PM_{10} by filter impactor concentrations (averaged continuous $PM_{2.5}$ (or PM_{10}) concentration divided by $PM_{2.5}$ (or PM_{10}) by filter mass concentration). This factor was applied to scale the real time data. A zero calibration was performed before each day using a zero filter which comes with the DustTrak DRX. Similarly, a daily flow calibration was performed with a Gilibrator flowmeter following procedures in Operation and Service Manual Model 8533/8534 (P/N 6001898, Revision F, January 2011). The DustTrak inlet was cleaned after each day with a cotton swab.

5.9.5.4 CO_2

CO_2 was continuously measured using an NDIR instrument (LI-COR 820 model, LI-COR Biosciences, Lincoln, NE, USA). This unit was configured with a 14 cm optical bench, giving it an analytical range of 0-20,000 ppm with an accuracy specification of less than 3% of reading. The LICOR was calibrated in accordance with U.S. EPA Method 3A [14] with three-point zero and calibration drift test. The LI-COR 820 CO_2 concentration was recorded every second on the onboard computer using the FlyerDAQ program. The calibration error for all test days was between 0.001 % and 0.559 %, and the system drift was between 0.015% and 0.319%, below the error and drift acceptance criteria of 5% and 3%, respectively, as stated by the U.S. EPA Method 3A [14].

5.9.5.5 CO

A Horiba Model VIA510 CO monitor (Horiba Instruments, Inc, Chicago Ill) was used on the side of the Flyer's CO_2 inlet during the paperboard tests (November 2014 test period). The analyzer operates by directing identical infrared (IR) beams through an optical sample cell and a sealed optical reference cell. A detector, located at the opposite end of the cells, continuously measures the difference in the amount of infrared energy absorbed within each cell. This difference was a measure of the concentration of the component of interest in the sample. The CO analyzer adheres to U.S. EPA Method 10 [15]. Calibration and post drift tests were performed each test day. The calibration error for all test days was between 0.01 % and 1.10 %, and the system drift was between 0.66 % and 1.57 %, below the error and drift acceptance criteria of 5% and 3%, respectively, as stated by the U.S. EPA Method 3A [14].

An electrochemical gas sensor (e2V EC4-500-CO, SGX Sensortech, Buckinghamshire, United Kingdom) was used for the MRE tests. This sensor measures CO concentration by means of an electrochemical cell through CO oxidation and changing impedance. The E2v CO sensor has a CO detection range of 1-500 ppm with resolution of 1 ppm and sensitivity of 55-85 nA/ppm. The response time was less than 30 seconds. The CO sensor was calibrated and tested for post-drift on a daily basis in accordance with U.S. EPA Method 3A. The system drift was between 0.168% and 4.993% (for one test day only, otherwise below 3%), which was both above and below the 3 % acceptance criterion as stated by the U.S. EPA Method 3A [14], respectively. For the test day where the drift was 4.993%, the calibration curve was used for the first half of the tests and the post-drift curve was used for the second half of the tests.

5.9.6.1 Emission factors

The emission factor for each species was calculated from the ratio of pollutant concentrations to background-corrected carbon concentration as calculated from CO_2 and CO measurements (ΔCO_2, ΔCO and ΔCH_4 for VOCs). Emission factors were calculated using these concentrations and the fraction of C in fiberboard/MRE material, following the carbon balance method [16]. This approach assumes that all carbon in the combusted material was emitted as CO_2, CO, and CH_4.

$$\text{Emission Factor (g Pollutant/g Material)} = Fc \times \frac{\text{Pollutant}\left(\frac{mg}{m^3}\right)}{\sum \text{Carbon}\left(\frac{mg}{m^3}\right)} \qquad \text{Equation 2 1}$$

where: Fc = carbon fraction in the fiberboard/MRE material, Carbon = amount of carbon sampled derived from ΔCO_2, and ΔCO (and ΔCH_4 for VOCs) concentration in the plume.

5.9.6.2 PCDD/PCDF Toxic Equivalent Calculations

PCDDs and PCDFs include 75 and 135 congeners, respectively. Of these 210 congeners, 17 are toxic and have been assigned TEF values [12] The TEQ value was obtained by multiplying the concentration of a PCDD/PCDF congener by its TEF-value and summarizing the result for all 17 toxic congeners. The U.S. EPA has listed 16 priority PAHs. Some of these PAHs are probably carcinogenic to humans according to U.S. EPA. Table 18 lists these 16 PAHs and their TEFs for humans.

Table 18. PCDD/PCDF Toxic Equivalency Factors for mammals/humans [12].

PCDDs	TEF	PCDFs	TEF
2,3,7,8 - TCDD	1	2,3,7,8 - TCDF	0.1
1,2,3,7,8 - PeCDD	1	1,2,3,7,8 - PeCDF	0.03
1,2,3,4,7,8 - HxCDD	0.1	2,3,4,7,8 - PeCDF	0.3
1,2,3,6,7,8 - HxCDD	0.1	1,2,3,4,7,8 - HxCDF	0.1
1,2,3,7,8,9 - HxCDD	0.1	1,2,3,6,7,8 - HxCDF	0.1
1,2,3,4,6,7,8 - HpCDD	0.01	1,2,3,7,8,9 - HxCDF	0.1
1,2,3,4,6,7,8,9 - OCDD	0.0003	2,3,4,6,7,8 - HxCDF	0.1
		1,2,3,4,6,7,8 - HpCDF	0.01
		1,2,3,4,7,8,9 - HpCDF	0.01
		1,2,3,4,6,7,8,9 - OCDF	0.0003

Table 19. PAH Toxic Equivalency Factors for humans [17].

Compound	TEF	Compound	TEF
Naphthalene	0	Benzo(a)anthracene[a,b]	0.005
Acenaphthylene	0	Chrysene[a,d]	0.03
Acenaphthene	0	Benzo(b)fluoranthene[a]	0.1
Fluorene[c,d]	0	Benzo(k)fluoranthene[a,b]	0.05
Phenanthrene[c,d]	0.0005	Benzo(a)pyrene[a,b]	1.0
Anthracene[c,d]	0.0005	Indeno(1,2,3-cd)pyrene[a,b]	0.1
Fluoranthene[c,d]	0.05	Dibenz(a,h)anthracene[a]	1.1
Pyrene[c,d]	0.001	Benzo(ghi)perylene[c,d]	0.02

[a] Probably carcinogenic to humans according to US EPA. [b] Probably and possibly carcinogenic to humans according to International Agency for Research on Cancer (IARC). [c] Not classifiable as carcinogenic to humans according to US EPA. [d] Not classifiable as carcinogenic to humans according to IARC.

Modified Combustion Efficiency

The modified combustion efficiency (MCE) (Equation 2-2) was a measure of combustion behavior or how well the fuel was being burned where MCE = 1.0 was complete combustion. The MCE can be categorized as MCE ≥ 0.95, indicating flaming conditions (good combustion) and MCE < 0.90, indicating smoldering conditions (poor combustion).

$$MCE = \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$$

5.9.6.3.1 Data Precision

The data precision was checked by calculating:

- Relative percent difference (RPD) for any pair of duplicates

$$RPD = 100 \times \frac{Q - B}{Q + B} \qquad \textit{Equation 2-3}$$

where: Q = results from one sample, B = results from replicate samples

- Standard deviation (STDV) if more than duplicate measurements were conducted

$$STDV = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \qquad \textit{Equation 2-4}$$

Wherewhere: μ = average results from all samples, x_i = results from one sample
N = number of samples

Or expressed as Relative Standard Deviation (RSD)

RSD = 100 X STDV / Average

Single factor one-way analysis of variance (ANOVA) with alpha of 0.05 (level of significance) was used to determine any differences between the four fiberboards types and between the four MRE waste compositions types. To establish significant difference the ANOVA returned p value (significant value) has to be less than the alpha value (0.05) and the F-distribution value (F/F_{crit}) has to be greater than 1.0.

5.10 Soldier Acceptance

Sustainability and Logistics Basing – Science and Technology Objective – Demonstration (SLBSTO-D) Technologies took place at the Camp Integration Lab (BCIL) – Fort Devens, MA 6-9 June 2016.

At the start of each focus group, Soldiers were paired off and given two boxes filled with MREs (the current fiberboard box and the test corrugated box). They were not given any information about the differences between the boxes or differences between the MRE packaging. This allowed the researchers to determine whether the Soldiers were able to recognize any of the modifications on their own.

5.11 Manufacturing

The coating was manufactured at Spectra-Kote as shown in Figure 40. The company was founded in 1958 in Gettysburg, PA. The Spectra-Kote coating was successfully designed and coated onto paper for this project. All formulations were developed with control for consistent quality from the manufacture of the coating to its application to the paper substrate. The products developed for the NSRDEC were specifically designed to meet the Army's requirements for strength, durability and enhanced stewardship for the sustainability of the supply chain. Figure 41 shows the blending of the coating that has to be of the correct viscosity for application along with the designed benefits for printability, glueablity and recyclability. Figure 42 shows how the coating formulations are characterized before they are coated onto paper. All of Spectra-Kote's products need to pass ISO 9001:2012 guidelines to ensure the quality of the coating. Figure 43 and Figure 44 shows coated rolls of paper during and after the coating has been applied. These coated rolls are ready to be sent to corrugator converters who will create the finished box specification set forth in the DoD Natick MRE Program.

Figure 40. Spectra-Kote, Gettysburg, PA

Figure 41. Blending the coating formulation

Figure 42. Characterizing the coating formulation

Figure 43. Coating paper with the Spectra-Kote

Figure 44. Coated Paper

5.12 Assembly Evaluation

5.12.1 Site Description - AmeriQual Packaging

A pre-trial demonstration of the MRE assembly process using the coated corrugated container was conducted at AmeriQual Packaging in Evansville, Indiana as shown in Figure 45 on the 12th-16th of July, 2013. AmeriQual Packaging was a 375,000 square foot packaging facility, which specializes in the custom assembly of meal kits, group feeding rations, variety and retail store packs. AmeriQual Foods, also in Evansville, operates a 250,000 square foot food processing facility, which prepares the MRE ration food. They are a leading supplier of individual rations including MRE, Humanitarian Daily Rations, Meal Cold-Weather/Long Range Patrol rations, and Tailored Operational Training rations. AmeriQual also specializes in the assembly of group rations to include both the "A" and "B" UGR, the UGR Express, and the UGR Heat and Serve. AmeriQual has continued to supply the U.S. military with millions of operational rations since 1996 and was an ideal location to demonstrate the assembly of the MRE using the coated corrugated shipping container.

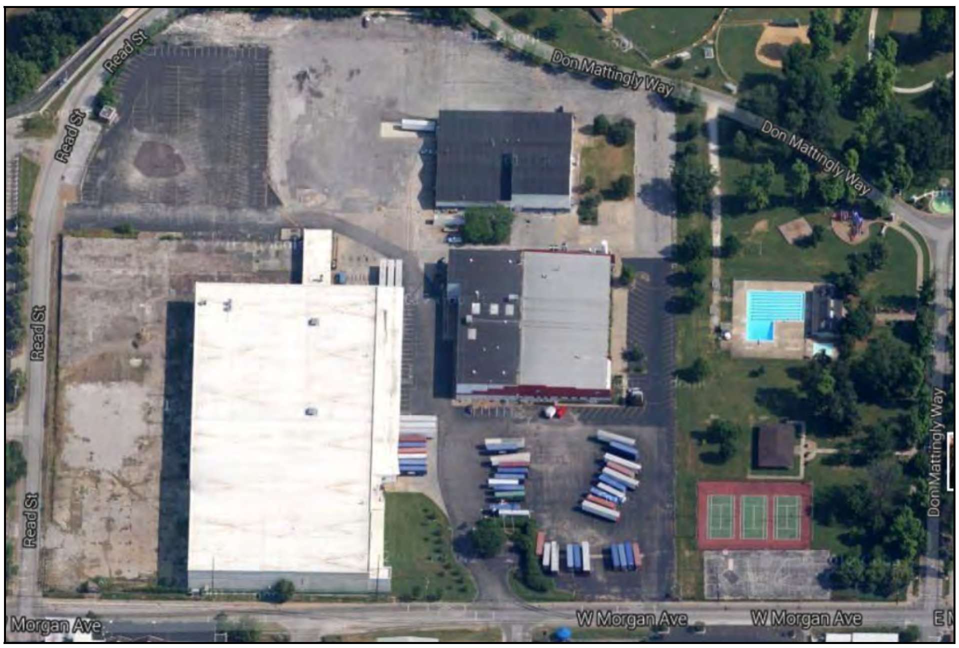


Figure 45. AmeriQual Packaging and Assembly Facility in Evansville, Indiana

On 15 February 2013, the Advanced Materials Engineering Team attended the pre-manufacturing trial at AmeriQual Packaging in support of the Environmental Security Technology Certification Program (ESTCP) project, "Lightweight and Compostable Packaging for the Military." The trial examined AmeriQual's case packing assembly line and evaluated the compatibility of new corrugated fiberboard MRE containers within AmeriQual's assembly operations and equipment. The trial produced over 100 assembled containers and two unitized loads for further product testing and follow-on inspections. Additionally, assembly parameters were identified and recorded for future manufacturing trials to support the manufacturing and assembling of 30 palletized loads. The full pallet loads were used throughout the demonstration project for in-the-field validation of new packaging design and included: long term storage study, over the road shipments, rough handling simulations, package testing and aerial delivery demonstrations. These efforts helped further transition new packaging designs and significantly reduce sustainment costs, minimize solid waste, diminish material costs, decrease number of transport vehicles, and streamline logistics operations for the Warfighter.

For the 6.4 demonstration/validation ESTCP project, the NSRDEC engineers needed to participate in this pre-assembly trial. This pre-trial utilized AmeriQual's facility to assess compatibility of new corrugated fiberboard MRE container with AmeriQual's assembly process. NSRDEC's expertise in fiberboard was needed to resolve any immediate on site assembly issues associated with the new corrugated container before a full production trial of 30 pallets followed in the third quarter of FY13. NSRDEC's engineers worked with AmeriQual to optimize the assembly parameters to accommodate the specialized glue and ink substrates for the corrugated containers. NSRDEC engineers also observed and documented the assembly operations for case packing and provided packaging support during the pre-trials to include first article inspection of the ration containers.

5.12.2 Demonstration Objectives

- Evaluate the compatibility of corrugated containers integrated into MRE assembly operations at AmeriQual Packaging
- Assess compatibility with packaging assembly equipment to include case erector, case sealer, strapping equipment, ancillary assembly equipment, conveyors, palletizing equipment and stretch wrapping operations
- Assess performance of adhesives in bonding with top and bottom flaps of coated materials
- Evaluate packing compatibility of 2013 rations to include fit/function of fully packed cases
- Identify line inefficiencies and incompatibility of materials associated with new packaging
- Identify trends in packaging defects and identify root cause of product damage incurred during assembly operations
- Identify major integration risks and identify necessary equipment modifications prior to 15 pallet demonstration trail in 4Q FY13

5.12.3 General Cased Packing Sequence

1. Case erecting of empty container (automated sealing Pearson Packaging Systems)
2. Insert corrugated liner (manually inserted by one person)
3. Pack menus 1-12 (manually inserted by 6 separate workers, inserting two each)
4. Case sealing of filled container (automated case sealing Klippenstein SK500 HM)
5. Printing (Date of pack, inspection date, and case identification (A/B))
6. Case banding (Automated strapping machine Dynaric ST1)
7. Case mixing of A/B cases (Automated equipment used to alternate cases on conveyor)
8. Labeling (Time temperature indicator and barcode)
9. Unit load palletization (loading and banding)
10. Stretch wrapping of unitized pallet

5.12.4 Pre Trial – Sample Preparation

The corrugated fiberboard containers made by York Containers during the case packing assembly trials and used for the ration assembly demonstration are shown in Figure 46. These containers were manufactured on January 8th, 2013 and shipped to AmeriQual Packaging prior to the trial demonstration in February. The bottom flaps were hand sealed using a hot melt adhesive and were hand packed with 12 rations each. The containers were inserted into the assembly line shortly after the case sealing equipment that erects the knocked down container. It was also placed into the assembly line after a section of fixed rails that guided the empty containers into a favorable position on the conveyors. Positioning of the containers closer to the line workers helped packing operations and improves the ergonomics of placing the rations into the bottom of the container. In total, two pallet loads were assembled consisting of 96 containers. Each unitized load were packed with a mixture of case A and B rations with 24 A cases (menu 1-12) and 24 B cases (menu 13-24) per load. During this trial run, only one of the two assembly lines was used to demonstrate the corrugated containers. All adjustments to equipment and ancillary equipment were performed on the case A assembly line and should be noted that any future adjustments would also need to be made on the case B assembly line to accommodate the new material and container size.

Figure 46. Corrugated test samples manufactured by York Containers on the AmeriQual MRE assembly line (left) and erected on a pallet (right)

5.12.4.1 Process 1 - Case Sealing (Bottom Flaps - Empty) - Pearson Packaging Systems case erector

The Pearson CE35 was an automatic case erector that was capable of erecting and sealing cases with hot-melt glue at speeds up to 35 cases per minute. The small footprint makes it ideal for production areas and an optional low-level, vertical magazine makes it easy to load blanks into the machine for erecting. During the trial run the cases were not erected and sealed by the equipment, however they were hand sealed by workers prior to case packing operations. The compatibility of material and equipment was validated during future production trials. It was important to note that prior to integration of new packaging design, an adhesive had to be identified and be compatible with the case sealing equipment and time-to-seal activities. From videos taken from actual operations (shown in Figure 47), it appears that an adhesive substrate would have to set in under 3 seconds and maintain that bond throughout assembly activities and operational use during its lifetime.

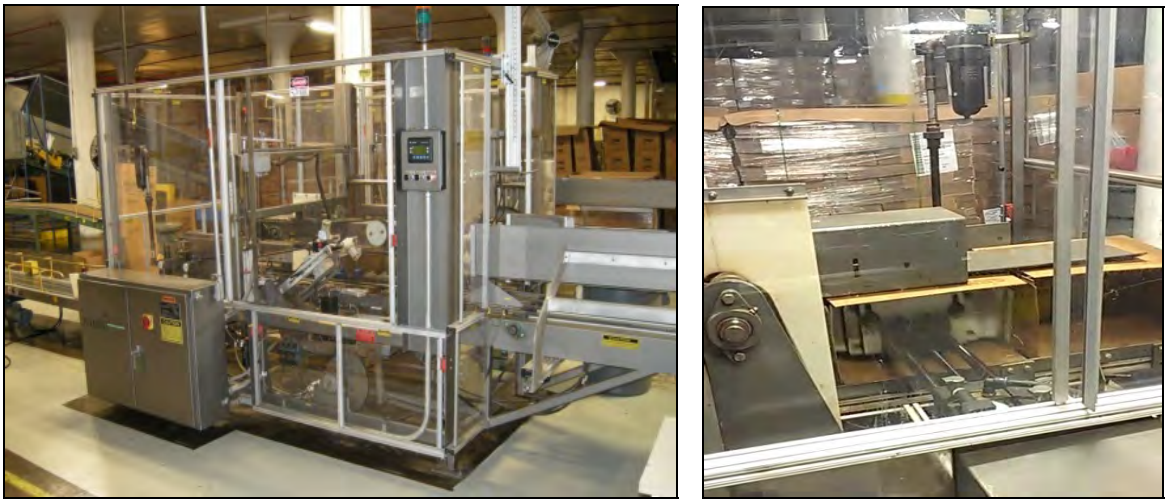


Figure 47. Full view of the case erecting equipment from Pearson Packaging Systems (left) and close up of the gluing of the container's bottom flaps (right)

5.12.4.2 Process 2 – Corrugated Liner Insertion

In normal operations, the knocked down containers would be erected by the case erecting/sealing equipment and placed on the conveyor for subsequent packing of rations. Immediately after the case sealing process, a corrugated sleeve was manually placed into the formed container as shown in Figure 48. The corrugated liner was later used in the final case sealing operations as it was lined with hot melt adhesive on the outside of the container and bonded to the major flaps. For the prototype container, a pad would be placed on the top of the containers to take in the glue and bond to the top flaps.

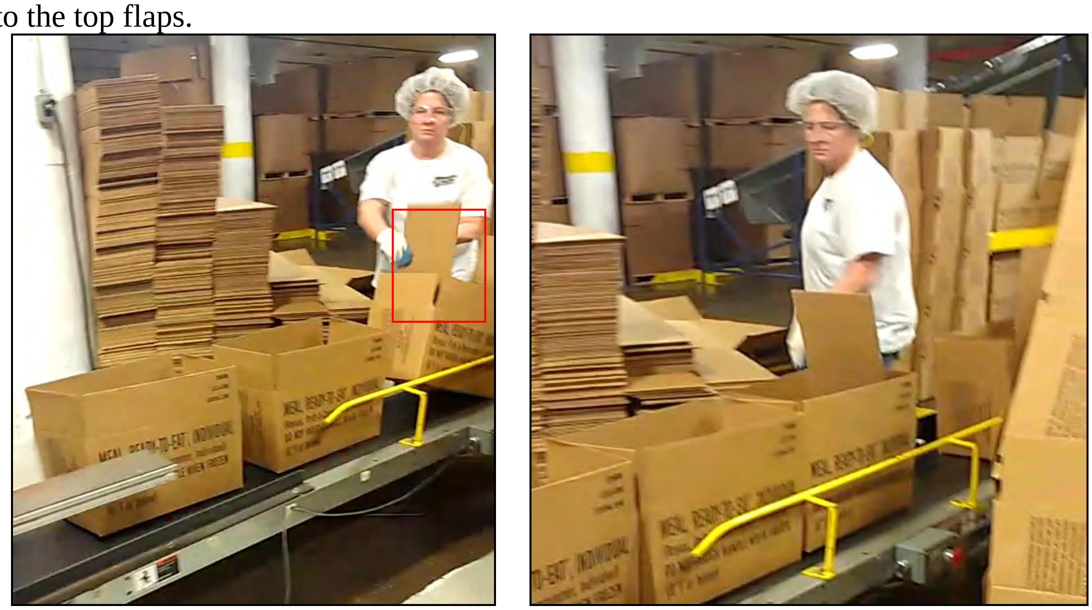


Figure 48. Manual insertion of corrugated liner into existing MRE Solid Fiberboard (SF) container highlighted in red (left) and on the case assembly line (right)

5.12.4.3 Process 3 - Filling of Rations

Once the corrugated liner was placed into the container, the empty boxes move down the conveyor to the first of 6 filling stations. At the first three filling stations the containers are angled towards the line worker to provide ease of packing into the bottom of case. The rail as shown in Figure 49 was fixed and as a result the larger corrugated containers were placed further down the line and filled accordingly. If a new container was integrated into assembly process, the rails were need to be modified to fit new size. These adjustments are minor in cost and labor invested in change. A different view of the MRE assembly line and filling station was shown in Figure 50.

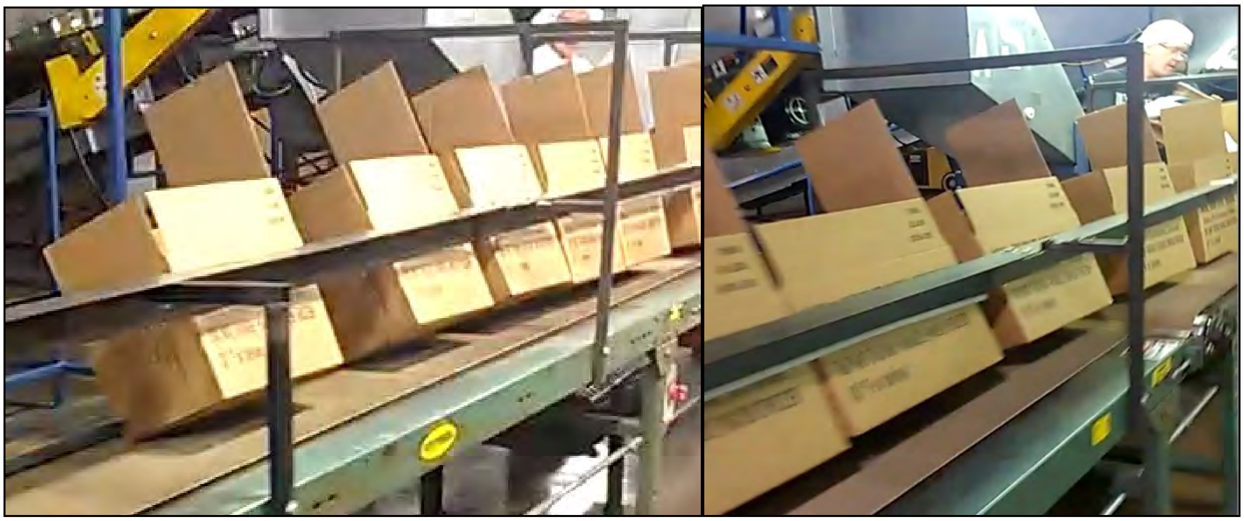


Figure 49: Fixed rail used to angle the containers towards line workers (left); rail tilted towards employee at filling station improving ergonomics and case packing activities (right)

Figure 50: AmeriQual Packaging assembly line (left) and MRE filling station (right)

Process 4 - Case Sealing (Top Flaps – Filled)

The Klippenstein SK500HM was designed and engineered for closing and sealing top flaps of fiberboard cases and was capable of adjusting the sealing parameters to accommodate smaller/larger containers and or alternative hot melt adhesives. This equipment was fully automatic for top sealing only and uses hot melt adhesive to seal each case. This model was a heavy-duty full length model, which has its own indexing conveyor to ensure correct positioning of the box in flap tucking and adhesive application section. It was equipped with vertical and horizontal crank screw adjusts for quick change over and can seal up to 40 cases per minute. During the trial run, the line speed was below the normal 22 cases per minute. The unit was pictured below in Figure 51 and in Figure 52. It was noticed that the adhesive used with the coated corrugated container failed to properly bond to the coated board as shown in Figure 53. Alternative hot melt adhesives have been identified by NSRDEC and were integrated into the August 2013 assembly run. During normal operations the case sealer applies glue to the top flaps and immediately after compress the flaps together, providing approximately five to seconds for sealing of the container before it was released from the top conveyor/rollers.

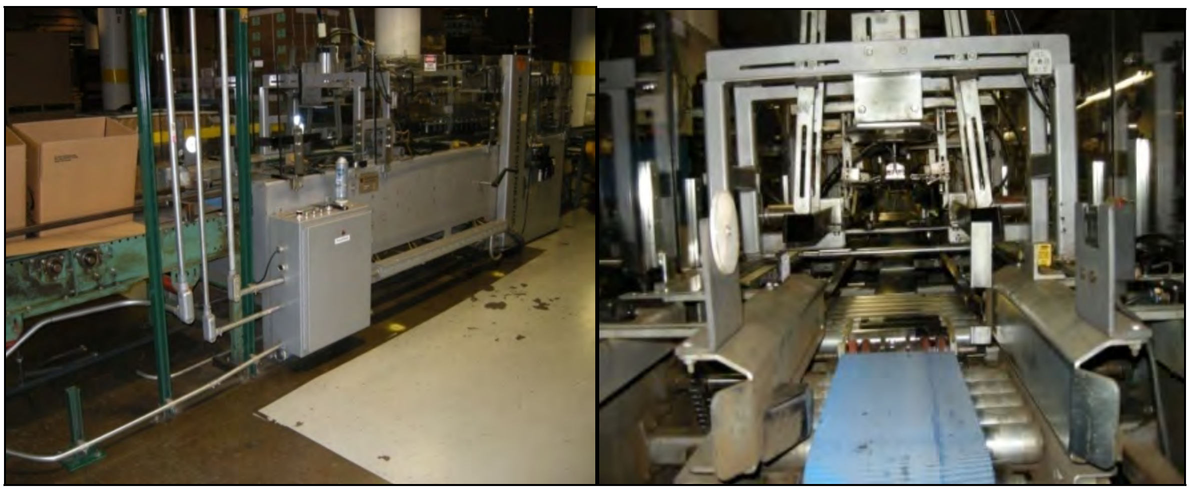


Figure 51. Klippenstein SK500 HM case sealing equipment for the top flaps (left) and view of the front entrance of the equipment (right)

Figure 52. Conveyor system used for securing glued flaps during curing of adhesive

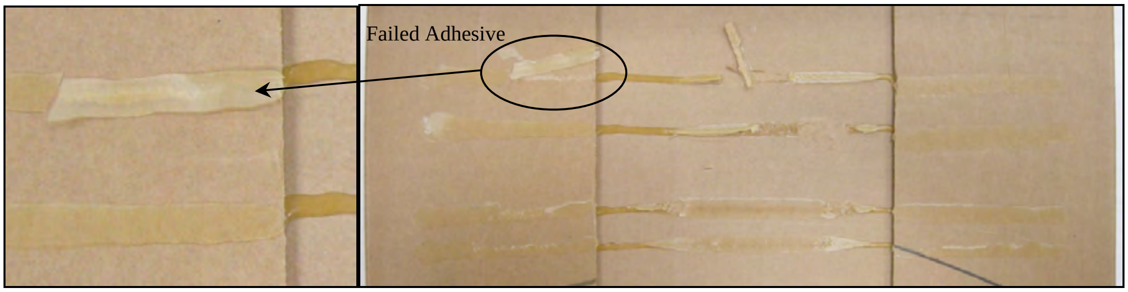


Figure 53. Adhesive application onto corrugated container (Note the failure of adhesive to bond to coated material)

5.12.4.5 Process 5 – Case Printing

Once the containers are sealed at the Klippenstein case sealer, the containers are then moved via conveyor to the Marsh LCP/ML8 printing station. At this station, the containers are labeled with three lines of print and include the date of pack on the first line, the inspection test date which was three years from the date of production and the case identification of A/B with the corresponding menu numbers, 1-12 or 13-24 respectively. During this trial run the printing heads were turned off and not used to print on the coated materials. In pre-trials, the ink was unable to bond to the surface of the container. The ink formulation needed to be changed prior to future integration of new coated materials. Shown in Figure 54 are images of the printing station at this stage in the process. Shown in Figure 55 was a fully printed MRE container. In addition to modifying the ink formulation, the case print layout needed to be changed to accommodate the new case size and orientation of the panels on the container.

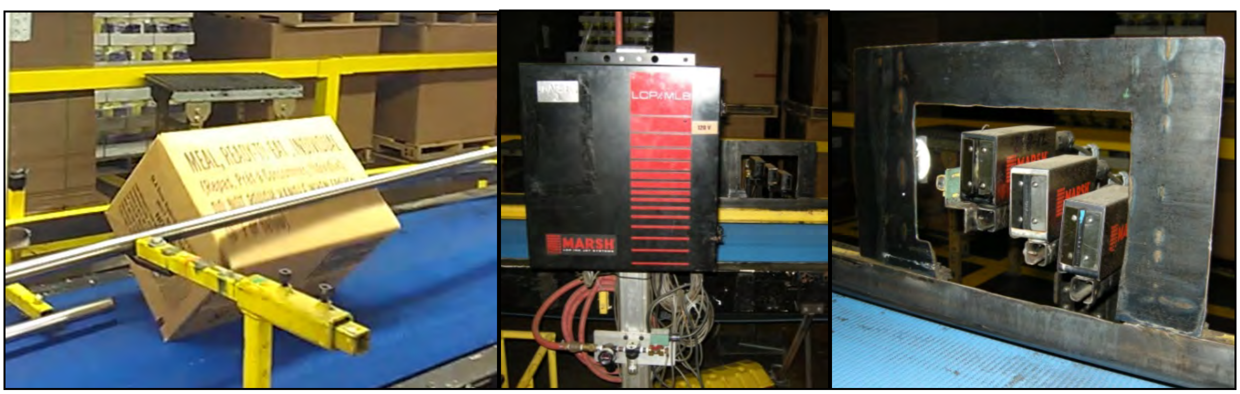


Figure 54: Orientation of container prior to print (left), Marsh LCP/ML8 printing station (middle) and three print heads (right) used to print the date of pack, inspection test date and case identification

Figure 55. Image of dot matrix printing from Marsh LCP/ML8 and case labeling of existing MRE SF container

5.12.4.6 Process 6 – Case Strapping

After the case sealing process at the Klippenstien, the packed containers were put through two strapping units as shown in Figure 56. The two units are from Dynaric, Inc. and are used to band the individual containers and provide additional securement or containment of the individual rations. The ST1 was a fully automatic strapping machine equipped with variable speed powered belts, eliminating the need for an operator. Although the unit can be switched to manual and used like an offline unit, the ST-1 was designed to operate automatically using adjustable photo switches to detect incoming packages. The ST1 can be customized to meet the requirements of any packaging environment. During the trial, the two units were not adjusted to accommodate the larger size case, and as a result, the straps were not correctly positioned on the case. It was recommended that adjustments be made to the photo switches/detecting unit in order to ensure optimal placement of the two straps, which was normally set in approximately three inches from the edge of the container.

Figure 56. Case Strapping equipment used to band individual containers (left) and the strapped case (right)

5.12.4.7 Process 7 – Mixing Operations

During normal operations both assembly lines run at the same time, one line (A) packing menus 1-12 and the other line (B) packing 13-24. Once the containers have been sealed and strapped on each line, they are then transported via a conveyor system to the sorting machine which automatically alternates both case A and case B so that when the containers are palletized they are mixed within each layer of the pallet load. During this operation there are two activities that mix the containers. The first activity involves a stop gate that holds the container in place while the alternating container moves down the conveyor. Once the container passes, the stop gate was released and allows one container on the opposite side to move along the conveyor, thus creating a line of alternating cases of A and B. During this operation, a cushioned plate behind the gate also holds the cases in place prior to mixing and was shown in Figure 57 on the left. During the trial run, it was recognized that the cushioned plate compressed the containers in excess and often times caused compression damage to the containers. This process could result in premature failure of the containers and may impact overall compression strength of the containers and also impact unit load compression strength of the palletized load.

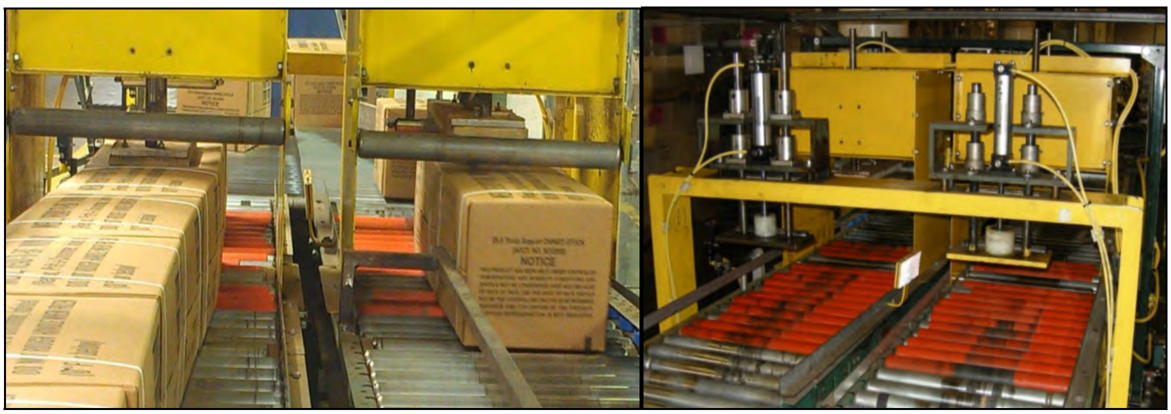


Figure 57. Case mixing equipment developed by AmeriQual Packaging (left) and a view of the front gate (right)

5.12.4.8 Process 8 – Labeling

From the case mixer, the assembled rations move up a conveyor to the first floor where they are labeled, inspected for damage and then palletized into a unit load. The process was shown in Figure 58 below. In this process, the barcode was applied to the case along with the time temperature indicator (TTI). Adjustments would need to be made with this equipment to ensure the barcode and TTI label was not placed on or near the strapping.

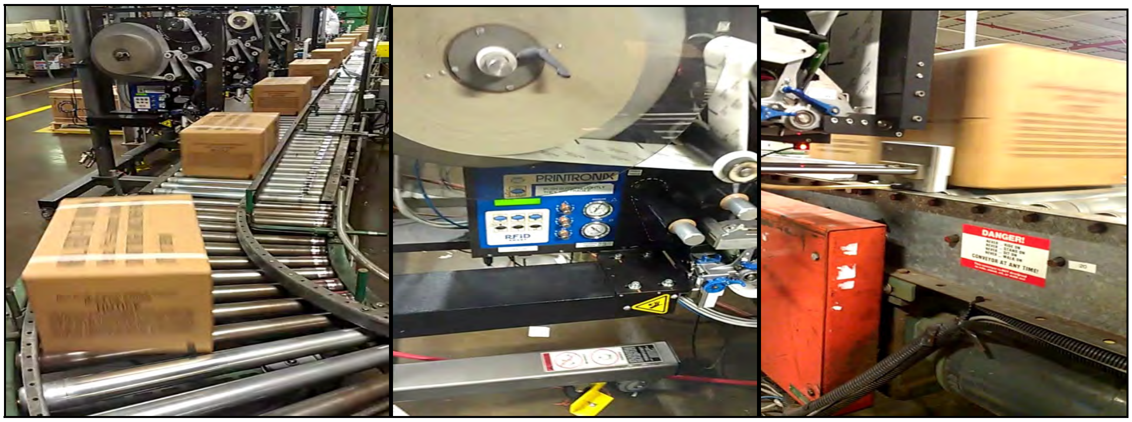


Figure 58. Labeling operations (left), barcode labeler (middle) and application of barcode (right)

5.12.4.9 Process 9 – Unit Load Palletization

Once the cases are labeled they are arranged into layers of alternating cases and create a three by four configuration that uses 12 cases per layer. This process was performed four times to build all the layers of the pallet which consisted of 48 cases per pallet load. A top cap was placed onto the top layer and the unitized load was moved to the strapping equipment. During unitization the cases are strapped three times with banding material. During the banding operation the pallet load was compressed several inches, severely compressing the containers and possibly damaging the containers. This unitization process was illustrated in Figure 59.

Figure 59. Images of the unitization of current MRE rations (48 cases per load) (left) and a fully-strapped unitized load (right)

5.12.4.10 Process 10 – Stretch Wrapping Operations

In this operation, the load remains in-place while a rotating arm turns around it wrapping the load. This system was commonly used for speeds which would otherwise cause the load to topple due to high rotation speeds. For MRE unit loads this was very much the case due to the pallet configuration and column stacks which improve compression strength but limit unit load stability. Often times the containers fall off the pallet during the start and stops near the stretch wrapper. Minimizing container bulging and proper stacking can help limit these occurrences. The unit load was wrapped approximately12 times with stretch wrap material as shown in Figure 60.

Figure 60. Stretch wrapping operations of unitized loads (automatic rotary arm stretch wrapper)

5.12.5 MRE Assembly Demonstration at AmeriQual Packaging

The full demonstration of the Meal Ready-to-Eat (MRE) assembly process using the coated corrugated container was conducted at AmeriQual Packaging in Evansville, Indiana on the 30th of July, 2013.

The goals of the assembly trial included all of the following:

- Assess compatibility of the corrugated container with AmeriQual facilities and packaging equipment, and compare it to the assembly of the control solid fiberboard containers
- Evaluate the assembly line process and identify integration risks
- Conduct first article inspection of packaged items
- Identify common packaging defects and failure trends
- Identify opportunities for improvement in the packaging and on the equipment
- Assemble 15 pallets of MREs with the coated corrugated containers and 15 pallets of MREs with control solid fiberboard for follow-on performance testing and demonstration/validation plans
  - Set-up long-term storage testing at Marengo Caves Warehouse and Distribution Center
  - Perform distribution and transportation studies
  - Perform air-drop trials
  - Perform field test
  - Perform compression strength testing (Tobyhanna LOGSA)
  - Perform composting testing
  - Perform re-pulping/recycling testing
  - Perform emissions testing
  - Perform insect penetration testing

5.12.5.1 Marengo Warehouse and Distribution Center

Storage demonstrations of the pallets were conducted at Marengo Warehouse and Distribution Center located in Marengo, Indiana. The Marengo Warehouse & Distribution Center was a vast complex of storage chambers and roadways originally constructed as a result of limestone mining using the classic room and pillar method. With its dry, stable indoor climate (58-60°F year round) and secure access, Marengo Warehouse offers a unique setting for storage of virtually any type of non-hazardous material. One of the world's most secure man-made vaults; Marengo was nearly a three-quarter mile square with nearly four million square feet of usable storage area. The hundreds of individual chambers and roadway corridors in Marengo are large enough for semi-trailer trucks to turn around comfortably without ever backing up. Marengo currently provides storage for millions of military rations and was a perfect location to demonstrate the long-term storage performance of the corrugated containers under evaluation through ESTCP. Illustrated in Figure 61 are images of this facility, which was a key distribution and storage site for the Defense Logistics Agency.

Figure 61. Marengo Warehouse entrance (left) and one of the internal storage chambers (right)

5.12.5.2 Demonstration Procedures

5.12.5.2.1 Stage 1: Pre-filling

Prior to the assembly demonstration, 15 pallets or 720 of the coated corrugated containers were manually glued and hand-filled offline by the AmeriQual employees. This step was necessary as one of the dimensions of the new containers was slightly too large for the beginning of AmeriQual's assembly line. The line can be altered to accept the dimensions of the new box, but it was un-reasonable to expect AmeriQual to make this large adjustment on their production line for this trial given that the line was being used to fill the current MRE shipping container for military ration procurement and would need to be adjusted back immediately following the trial. The 15 pallets of control containers were assembled prior to the trial, using the case erecter for sealing the bottom flaps of the container and were assembled under standard line conditions. This was done prior to the demonstration trial so that minor adjustments could be made to the line for running the corrugated container. The bottom flaps of the corrugated container were hand-glued prior to the demonstration. AmeriQual typically runs two lines for MRE production ("A" and "B" lines), but only line "A" was used in this demonstration in order to minimize line adjustments. If the corrugated container was accepted for use with the MRE, both lines need to have adjustments made to accommodate the new container dimensions. Figure 57 illustrates the filled containers after manual filling by AmeriQual.

5.12.5.2.2 Stage 2: Glue/Seal/Band

Once the pre-filled containers were loaded on to the assembly line, they entered the automated part of the assembly process which was closely examined in order to identify any areas which could cause a manufacturing problem that could lead to slower production speeds or failures in the containers. The containers first entered the glue applicator where a double bead of glue (Ad-Tech 612 hot melt adhesive) was applied to the underside of the two closure flaps at a temperature of 380°F. This was a different grade of glue than what was currently used on the MRE solid fiberboard container due to the water-resistant coating applied to the corrugated container. It was found that the original grade of glue did not cure in time to be effective on the new container and therefore a new grade was selected for use during this demonstration trial. Besides the change to the new glue, a secondary modification was made to the AmeriQual line which maintains a closure force to the top of the container for an additional 2 feet on the assembly line. This gives the new glue additional time (total of approximately 7 seconds) to cure once the container was closed. This modification aided in extending the cure time of the glue. It was noted that although this modification improved the closure seal, AmeriQual engineers recommended a different glue to enhance the closure seal even further. This cost/benefit of alternative glues needs have to be considered in the total cost of the corrugated container. Pictured in Figure 62 are the Klippenstein case sealer and the sealing/closing of the container with the new glue. Figure 62 on right shows the extension that was added to the line in order to maintain a closing pressure on the container for a longer period of time to allow for a better cure of the glue.

Figure 62. Case sealer prior to (left) and after (right) the closure seal modification

The assembly showed that the new containers did not have any problem during this stage of the process. Changes that would be recommended would be the permanent installation of the fixture which adds closing pressure for an additional length of the line and an investigation into a different grade of glue that would provide a better seal strength and quicker cure time.

5.12.5.2.3 Stage 3: Strapping and Case Configuration

Once closed and sealed, the containers travel through the strapping equipment which applies two straps around the case. These straps maintain a constant closing pressure on the boxes and, although not intended, are used by Soldiers to carry and move the containers around. The strapping equipment and process was shown in Figure 63. It was noted that due to the added length of the new container, some of the straps were misaligned on the container. A solution to this problem was to reprogram the timing of the strapping unit to accommodate the dimensions of the new container. The new containers did not show any other problems associated with this section of the trial.

AmeriQual's assembly processes uses two lines to ensure that each pallet of MREs contain a variety of meals. Rations are configured in both "A" and "B" containers which indicate the type of menus that are packaged within the container. To ensure that each pallet contains the same amount of both "A" and "B" containers, AmeriQual uses a system which staggers the sealed containers as they make their way to the palletizing unit. A mechanical system applies pressure to the top of the "A" containers to hold it in place while the "B" container was allowed to pass. After the "B" container passes, the pressure was then applied to the line of "B" containers in order to allow container "A" to pass. During the demonstration trial, it was observed that the pressure placed downward onto the top of the containers caused the top of both the corrugated and control fiberboard containers to deflect a small amount while it was waiting to be released to the palletizing machine. This deflection could be seen in the containers after being released and some pre-mature container damage was observed. This damage had a negative effect on the overall compression and stacking strength. It was determined if this deterioration of strength affected the overall stability and performance of the container or if the device that holds the containers needs to be altered in some way. This section of the line was shown in Figure 63.

Figure 63. Deflection of containers caused by the pressure of the container staggering system

5.12.5.2.4 Stage 4: Palletizing

Stage 4 of the process began once the sealed and strapped containers leave the staggering system and headed upstairs to the palletizer. At this point, the containers were assembled into pallets containing 48 containers of MREs. Each pallet consisted of 4 layers of containers, with each layer containing 12 containers. Each pallet was covered with a cap sheet which was used to stabilize the layers during the wrapping phase and during transportation. It was found that the cap used for the current solid fiber board shipping container would have to be re-sized to fit the dimensions of the new container properly. The location of the score/fold lines on the cap needed to be adjusted as the current location of these folds do not line up with the edge of the pallet using the new containers. This issue was illustrated in Figure 64 below.

Figure 64. First level of containers in the palletizer (left) and the problem identified with the location of the cap folds on pallets of new containers (right)

It was also observed during the palletizing process, that the combination of both "A" and "B" containers on the same pallet lead to an uneven top surface due to the differences in menu size. This issue was observed in both the control and corrugated containers and was mitigated through the use of strapping and pallet wrap once in the palletizer. This pattern creates an uneven stacking surface and could cause more damage than usual to the larger containers ("B" containers) as they would support more of the load forces. A potential solution would be to layer the containers differently with alternating "A" and "B" container layers until a full pallet was constructed. This would balance out the pallet and create a flat stacking surface. Figure 65 shows the strapping unit that compresses the containers and applies three straps to the pallet load for stability prior to being stretch-wrapped.

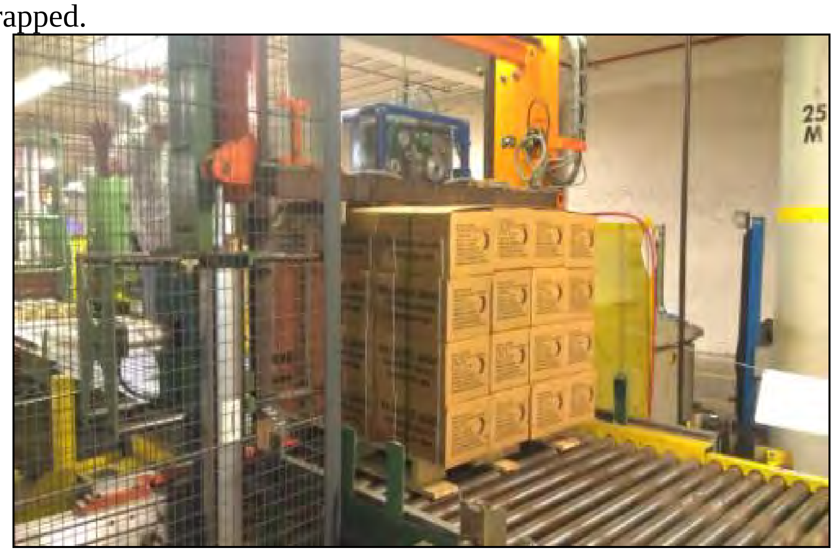


Figure 65. Pallet strapping unit (3 straps per pallet)

In total, 30 pallets of MRE shipping containers were packed and wrapped according to the testing plan. This included 15 pallets of control solid fiberboard containers and 15 pallets of the corrugated shipping containers, as shown in Figure 66.

Figure 66. Thirty pallets of MREs at the AmeriQual packaging center

5.12.5.2.5 Stage 5: Transportation and Storage at Marengo Caves

The finished pallets were then picked up at AmeriQual Packaging and shipped to Marengo Caves Warehouse and Distribution Center, located approximately 90 miles east of Evansville, Indiana. Once at Marengo, the pallets were positioned in one of the storage areas used to store rations in the military logistics system. In order to determine long term strength and stability of the new containers in comparison to the current containers, four stacks of MRE pallets were assembled in one of the MRE storage areas along with the remaining pallets at a two pallet stacked configuration. Each stack consisted of four pallets of MREs placed on top of each other. The stacks of pallets included two stacks of control MREs in solid fiberboard containers and two stacks of MREs in corrugated containers. A measurement system was set-up in order to measure any deflection of the stacks over time due to the weight of the stacked pallets. See Figure 67 for a picture of the stacks and the deflection measurement system.

Aside from the stored containers at Marengo, pallets of control and corrugated containers were shipped to the NSRDEC for closer inspection. Defects and problems that were inspected for include:

- Punctures in the container
- Crushing of the bottom side of the container
- False scoring on the top flaps
- Glue bonding on the top and bottom flaps
- Container crushing
- Misaligned straps
- Minor flaps pushed out
- Excessive container gaps

All of these defects were identified as possible problems after the pre-trial work done in preparation for the demonstration

Figure 67. Stacks of MRE cases at Marengo Caves (left) and the deflection measurement system (right)

6.0 PERFORMANCE ASSESSMENT

6.1. Reduction in Weight

The values of the weight of the containers with strapping in the “as received” condition, the container without strapping, and the container without contents (box only) in grams are in the table below.

Table 20. Weights of Containers in grams

Specimen	Box Type	Meal Bag Type	Case	“As Received” Weight with Strap	Weight without Strap	Box only
1	Solid	Current	A	9389	9383	989
2	Solid	Current	A	9363	9358	992
3	Solid	Current	B	8672	8667	986
4	Corrugated	Current	A	9244	9239	859
5	Corrugated	Current	B	8572	8566	844
6	Corrugated	Current	B	8654	8649	848

Some significant observations include:

- The mean weight of Case A was 9292.67g and the mean weight of Case B was 8606.22g.
- The weight of the strapping was between 4 and 6 grams.
- The mean of the solid fiberboard box was 985.22g and the mean of the corrugated fiberboard box was 849.22g.

The values of the weight of each meal bag in each container that was weighed empty are listed in the tables below. The old style meal bags was comprised of the brown blown bag and an inner thermoformed clear bag, labeled the primary bag and secondary bag, respectively.

6.1.1 EDA of Weight

6.1.1.1 Univariate Analysis of Response Variable (Overall Weight)

The descriptive statistics (Table 22) of the overall weight examined by outer box type indicates that the overall mean of the corrugated fiberboard (8802 g) was less than the overall mean of the solid fiberboard (9097 g). This was also shown in Figure 68, the histogram of the means weight when grouped by outer box.

Table 21. Descriptive Statistics of Overall Weight by Secondary Container (Outer Box)

Descriptive Statistics: Weight

Variable	Outer Box	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Weight	Corrugated	9	8802	320	8523	8568	8650	9201	9269
	Solid	9	9097	350	8562	8672	9280	9369	9389

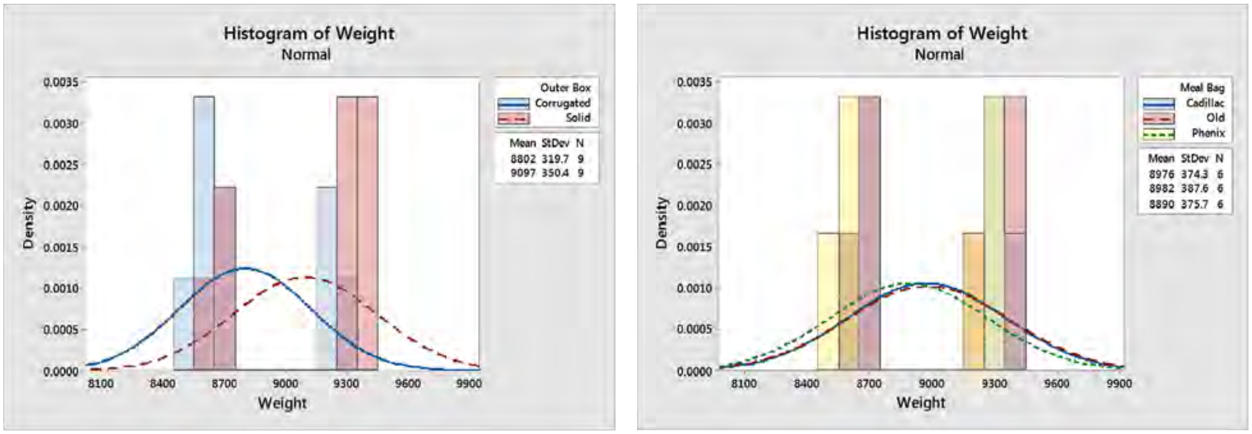


Figure 68. Histogram of Overall Weight by Outer Box

The descriptive statistics (Table 21**)** of the weight when examined by the different meal bags appears to indicate that the overall weight attributed to the meal bags was not significant. It was easier seen on the histogram (Figure 68) that the Phenix has a mean that was slightly less than the current meal bag assembly or the Cadillac thermoform bag, but this does not appear to be significant.

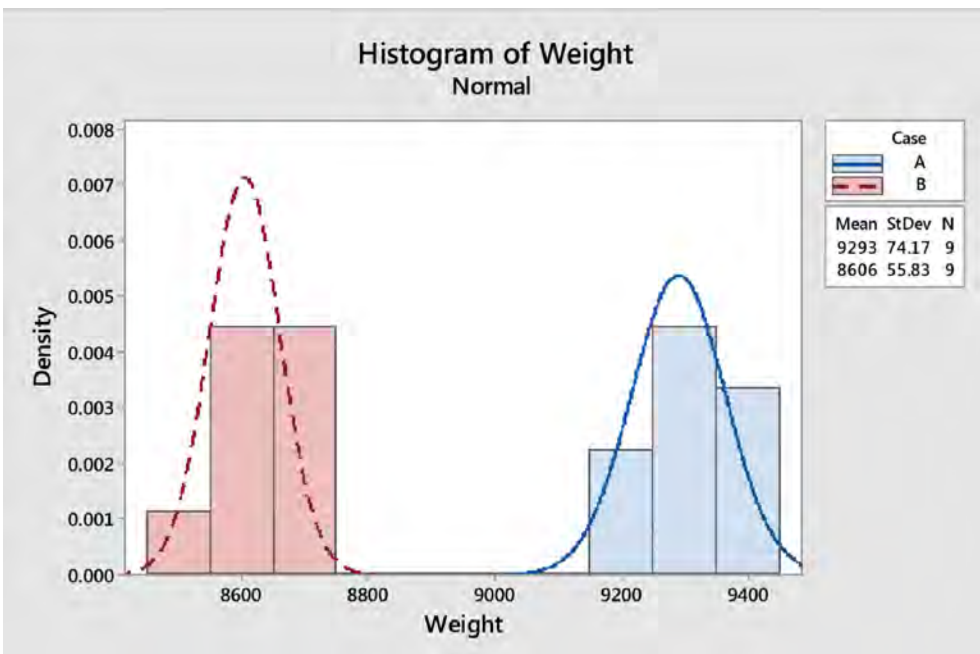


Figure 69. Histogram of Overall Weight by Case

The Scatterplot of Contents was plotted by groups which are the different cases, Case A and Case B (Plot 4). The scatterplot shows that the meals of Case A are scattered about an axis above Case B, indicating that the weights of the meals of Case A are greater than the meals of Case B. The histogram (Plot 5) also shows the difference in the weights of the contents by Case.

Because the data does not take into account the variability of weight due to different meals (Case A or Case B) and the variability of contents (denser foods, missing packets, etc.), the outer box types were examined solely on the weight of the outer box without contents.

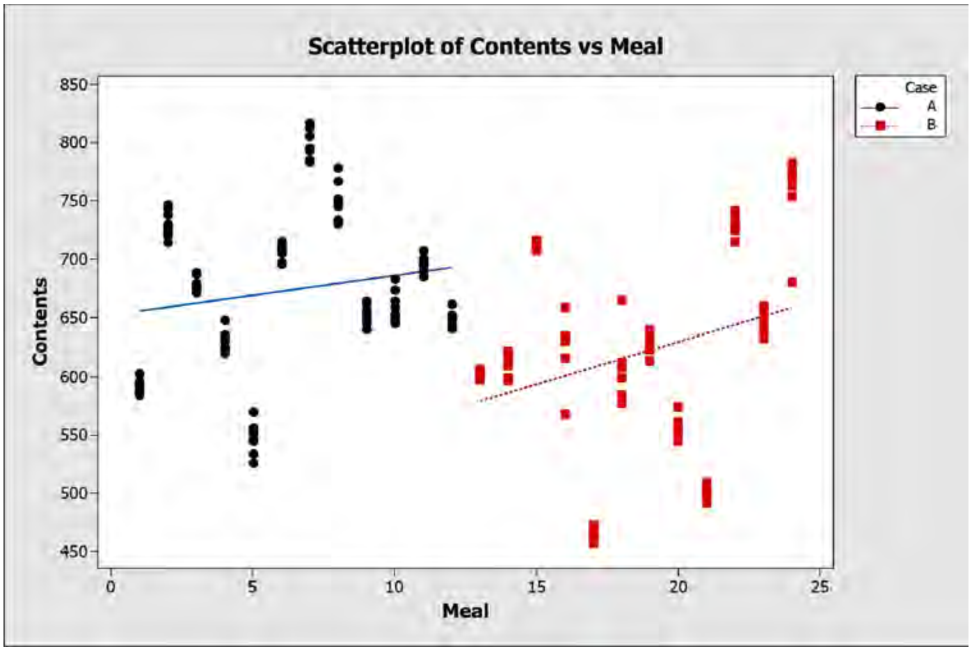


Figure 70. Scatterplot of Meals by Case

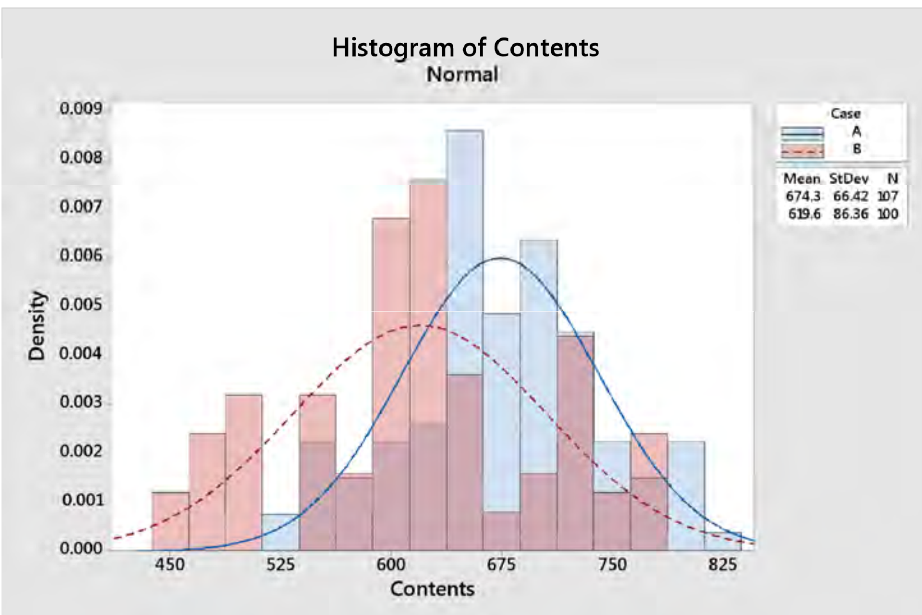


Figure 71. Meal Contents Weight By Case

6.1.1.2 Univariate Analysis of the Weight of the Outer Box

The descriptive statistics (Table 22) indicate that the mean of the corrugated fiberboard was approximately 850 grams, while the mean of the solid fiberboard was approximately 985 grams. The boxplot and histogram show no overlap indicating that there was a significant difference between the mean of the corrugated and the mean of the solid fiberboard outer box. A Two-Sample T-test (

Table 23) was performed to determine if the difference in mean weight of the outer box was statistically significant, through testing a null and alternative hypothesis. The null hypothesis (H_0) was that the mean of the corrugated fiberboard (μ_1) minus the mean of the solid fiberboard (μ_2) was equal to zero.

$$H_0: \mu_1 - \mu_2 = 0$$

If this was true, then the difference was not statistically significant. If it was rejected as true, then the alternative hypothesis was concluded to be true. The alternative hypothesis (H_a) was that the mean of the corrugated fiberboard outer box (μ_1) minus the mean of the solid fiberboard outer box (μ_2) was less than zero.

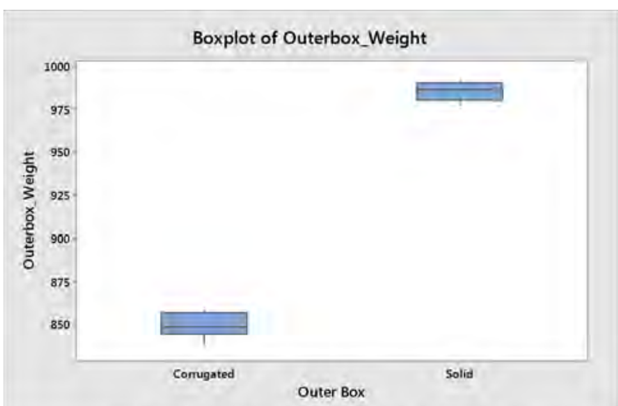
$$H_a: \mu_1 - \mu_2 < 0$$

Because the P-value< 0.05 (P-value = 0.000), the null hypothesis was rejected and the Two-Sample T-test indicates that difference was significant. The T-test indicates that the difference of the mean of the corrugated fiberboard outer box (μ_1) was approximately 135g less than the mean of the solid fiberboard outer box (μ_2).

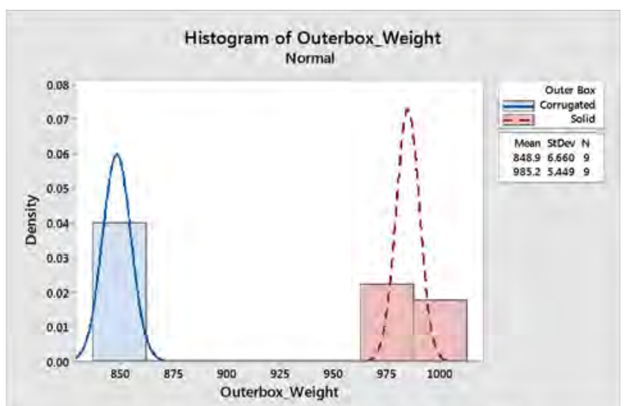
Table 22. Descriptive Statistics of Outer Box

Descriptive Statistics: Outerbox_Weight

Variable	Outer Box	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Outerbox_Weight	Corrugated	9	848.89	6.66	838.00	844.00	848.00	856.00	858.00
	Solid	9	985.22	5.45	977.00	980.00	986.00	990.00	992.00



Plot 6. Box Plot of Outer Box Weights



Plot 7. Histogram of Outer Box Weight

Figure 72. Box Plot of Box Weights

Table 23. ***T-Test of Outer Box Weights***

Two-Sample T-Test and CI

* NOTE * Graphs cannot be made with summarized data.

Sample	N	Mean	StDev	SE Mean
1	9	848.89	6.66	2.2
2	9	985.22	5.45	1.8

Difference = mu (1) - mu (2)
Estimate for difference: -136.33
95% upper bound for difference: -131.30
T-Test of difference = 0 (vs <): T-Value = -47.53 P-Value = 0.000 DF = 15

The descriptive statistics and Two-Sample T-Test (Table 6 and 7, respectively) show the difference in mean weights of the outer box are not significantly different based on the case.

Table 24. ***Descriptive Statistics of Outer Box by Case***

Descriptive Statistics: Outerbox_Weight

Variable	Case	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Outerbox_Weight	A	9	939.4	70.4	838.0	850.0	979.0	990.0	992.0
	B	9	894.7	66.7	844.0	847.5	856.0	982.0	986.0

Table 25. ***T-Test of Outer Box by Case***

Two-Sample T-Test and CI

Sample	N	Mean	StDev	SE Mean
1	9	939.4	70.4	23
2	9	894.7	66.7	22

Difference = mu (1) - mu (2)
Estimate for difference: 44.7
95% CI for difference: (-24.2, 113.6) T-Test of difference = 0 (vs not =): T-Value = 1.38 P-Value = 0.187 DF = 15

The null hypothesis (H_0) was that the mean of the corrugated fiberboard outer boxes of Case A (μ_1) minus the mean of the solid fiberboard outer boxes of Case B (μ_2) was equal to zero.

$$H_0: \mu_1 - \mu_2 = 0$$

Again, if this was true, then the difference was not statistically significant. If it was rejected as true, then the alternative hypothesis was concluded to be true. The alternative hypothesis (H_a) was that the mean of the corrugated fiberboard outer boxes of Case A (μ_1) minus the mean of the solid fiberboard outer boxes of Case B (μ_2) was different than zero.

$$H_a: \mu_1 - \mu_2 \neq 0$$

The P-value=0.187 was greater than 0.05, therefore we conclude there was not a difference.
Univariate Analysis of the Weight of the Meal Bag

The descriptive statistics and one-way ANOVA (Table 8 and 9, respectively) show the difference in mean weights of the different meal bag types are significantly different. The null hypothesis (H_0) was that the mean of the current meal bag (μ_1) was equal to the mean of the Cadillac meal bag (μ_2) was equal to the mean of the Phenix Meal Bag (μ_3).

$$H_0: \mu_1 = \mu_2 = \mu_3$$

If this was true, then the type of meal bag does not have an effect on the weight of the meal bag. If it was rejected as true, we would conclude that the alternative hypothesis was true. The alternative hypothesis (H_a) was that at least one mean was different.

The P-value=0.000 was less than 0.05, therefore we conclude there was a difference. Additionally, the one-way ANOVA for the Meal Bags (Table 9) includes the confidence intervals and because there was no overlap in the confidence intervals, it can be concluded that the means are different. The boxplot and histogram (Plots 8 and 9, respectively) also show that there was no overlap among the three meal bag types, which indicates a significant difference.

The packaged assembly represents the experimental unit and the combination of outer box type (solid or corrugated fiberboard) and the inner meal bag (current, Cadillac, or Phenix) with the respective Case (Case A or Case B) represent the treatments. We use Minitab to model the individual factors – Outer Box, Meal Bag, and Case – with all their interactions for the response variable – Weight.

The four-in-one plot shown in Plot 10 provides information regarding the ANOVA assumptions. All ANOVA analyses assume that:

1. Independence - The observations are independent.
2. Normality - The residuals are normally distributed.
3. Equal Variance – The variances of the data groups are equal.

When assessing independence, we examine the Residual Versus Order plot on the bottom right corner. An erratic line indicates no pattern over time and supports the assumption that the observations are independent.

The Normality Probability plot in the upper left corner and the Histogram of Residuals in the bottom left corner are examined when determining if the residuals are normally distributed. The Normality Probability plot shows the residuals are very close to the line and the histogram shows a bell-like plot. Both support the assumption of normally distributed residuals. From the Residuals Versus Fits plot in the upper right corner, we see the points are scattered about the centerline equally. The banded pattern indicates that the variances are equal and support the assumption stated above. After validating the assumptions, we can accept that the conclusions we draw from the analysis can be trusted.

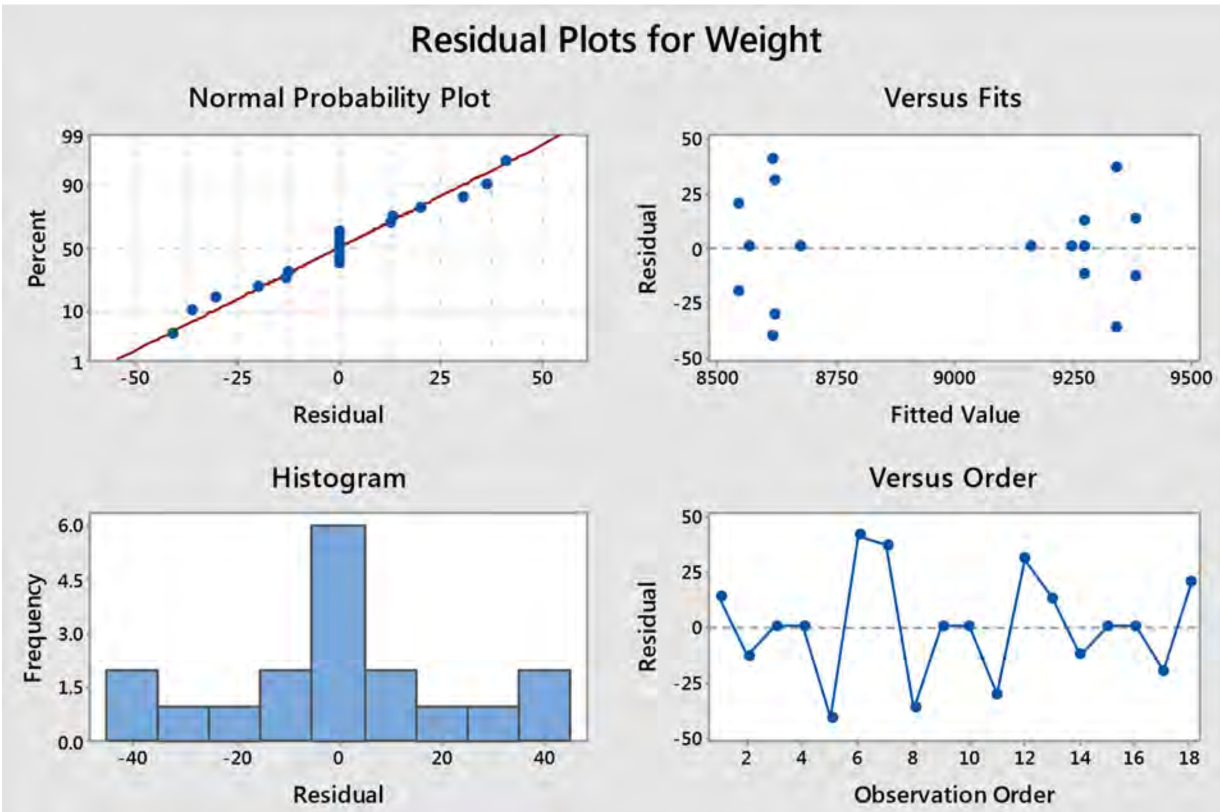


Figure 73. Four in One Plot of Overall Weight

The ANOVA tests the following null and alternative hypotheses:

- H_0: All treatment means are equal.
- H_a: Not all treatment means are equal.

By examining the p-values of the factors, we determine if the means are equal or if at least one was different. When we look at the output in Table 10, we examine the source factors and interactions for indication of a p-value less than the set significance level of 0.05. Factors or interactions whose p-value was less than 0.05 would cause us to reject the null hypothesis and conclude that the treatment means are not equal. This would mean the factor has an effect on the response variable.

We start by examining the interaction effects. The three-way and all two-way interactions have a p-value greater than 0.05, which means we would accept the null hypothesis and conclude that the interaction does not have an effect on the response variable: weight.

Next, we examine the individual factors and see that the p-values for each of the factors was less than 0.05 (bcurrented). This means that we reject the null hypothesis and conclude the Outer box, Meal Bag, and Case have an effect on the overall weight of the package.

6.1.2 EDA OF DEFECTS

6.1.2.1 Univariate Analysis of Response Variable (Defects)

The descriptive statistics (Table 26) of the overall number of defects examined by outer box type indicates that the overall mean of the solid fiberboard outer box (1.222) was less than the overall mean of the corrugated fiberboard outer box (1.333 g). This minor difference was not shown in the histogram.

Table 26. Descriptive Statistics of Number of Defect by Outer Box

Descriptive Statistics: Defects count

Variable

Outer Box	N	Mean	StDev	Minimum	Q1	Median	Q3	Maximum Defects count
Corrugated	9	1.333	0.707	0.000	1.000	1.000	2.000	2.000
Solid	9	1.222	1.302	0.000	0.000	1.000	2.000	4.000

A Two-Sample T-test (Table 27) was performed to determine if the difference in mean number of defects of the outer box was statistically significant, through testing a null and alternative hypothesis. The null hypothesis (H_0) was that the mean number of defects of the corrugated fiberboard ($\mu 1$) minus the mean number of defects of the solid fiberboard (μ_2) was equal to zero.

$$HH_0: \mu\mu_1 - \mu\mu_2 = 0$$

If this was true, then the difference was not statistically significant. If it was rejected as true, then the alternative hypothesis was concluded to be true. The alternative hypothesis (H_a) was that the mean number of defects of the corrugated fiberboard outer box ($\mu 1$) minus the mean number of defects of the solid fiberboard outer box ($\mu 2$) was not equal to zero.

$$HH_{aa}: \mu\mu_1 - \mu\mu_2 \neq 0$$

Because the P-value = 0.826, was greater than 0.05, therefore we conclude there was not a difference.

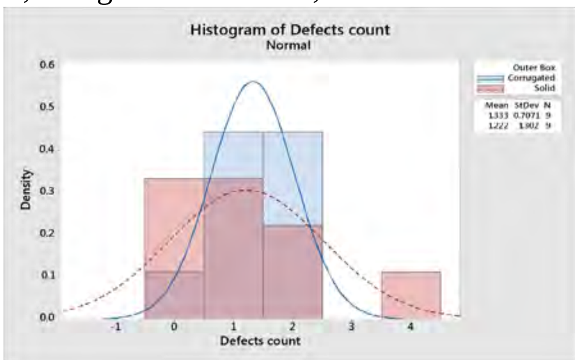


Figure 74. Histogram of Number of Defects by Outer Box

Table 27. T-Test of Number of Defects by Outer Box

Two-Sample T-Test and CI

Sample N Mean ST Dev SE Mean Corrugated
9 1.333 0.707 0.24
Solid 9 1.22 1.30 0.43

Difference = μ (1) - μ (2)
Estimate for difference: 0.111

```
95% CI for difference:  (-0.965, 1.187)
T-Test of difference = 0 (vs ≠): T
```

-Value = 0.22 P-Value =).826 DF = 12

This was performed to determine if the difference in mean number of defects by Case was statwastically significant, through testing a null and alternative hypothesis. The null hypothesis (H_0) was that the mean number of defects of Case A (μ_1) minus the mean number of defects of Case B (μ_2) was equal to zero.

$$HH_0: \mu\mu_1 - \mu\mu_2 = 0$$

If this was true, then the difference was not statistically significant. If it was rejected as true, then the alternative hypothesis was concluded to be true. The alternative hypothesis (H_a) was that the mean number of defects of Case A (μ_1) minus the mean number of defects of Case B (μ_2) was not equal to zero.

$$HH_{aa}: \mu\mu_1 - \mu\mu_2 \neq 0$$

Because the P-value = 0.109, was greater than 0.05, therefore we conclude there was not a difference at this level of significance. However, because it was very close to 0.1, further analysis should be done to determine if more samples would be more conclusive.

6.1.2.2 Full Analysis of Defects

The packaged assembly represents the experimental unit and the combination of outer box type (solid or corrugated fiberboard) with the respective Case (Case A or Case B) represent the treatments. We use Minitab to model the individual factors – Outer Box, Meal Bag, and Case – with all their interactions for the response variable – Number of Defects.

The four-in-one plot shown in Figure 75provides information regarding the ANOVA assumptions. The assumptions are validated for this analysis similarly to the previous analysis.

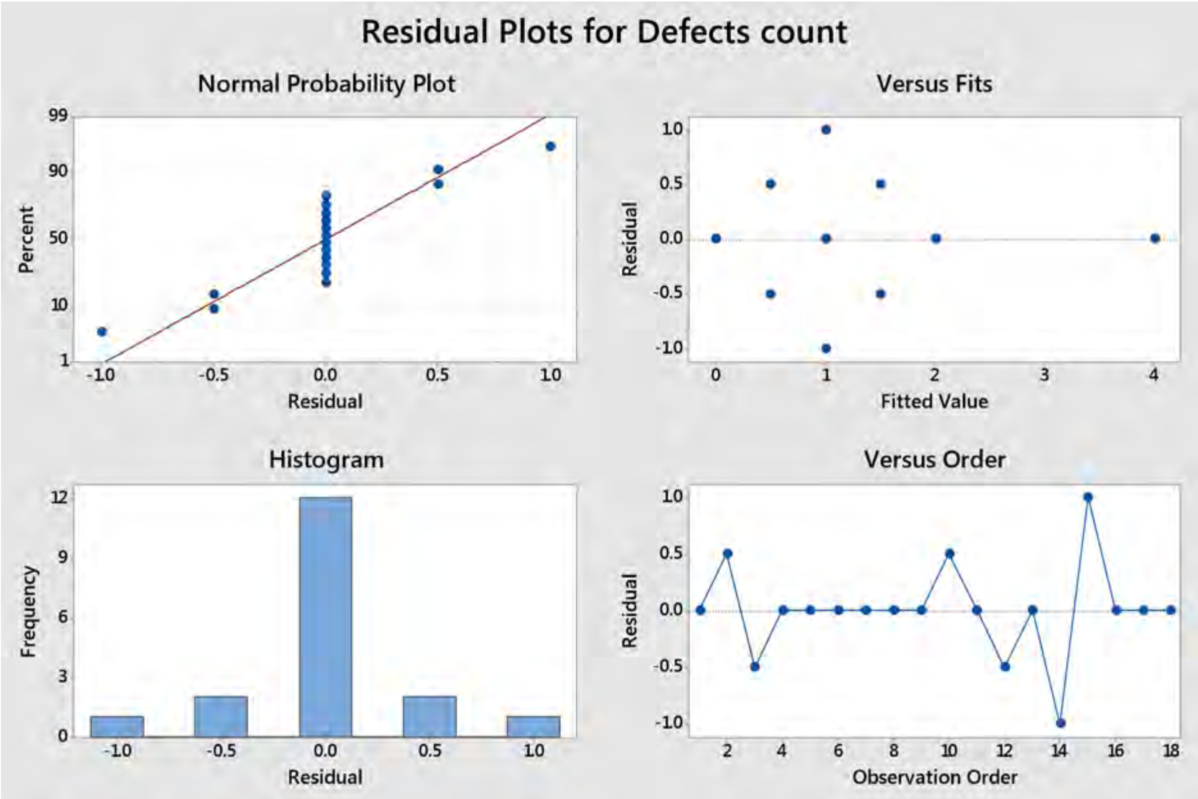


Figure 75. Four-in-one Plot of Number of Defects

The ANOVA tests the following null and alternative hypotheses:

- H_0: All treatment means are equal.
- H_a: Not all treatment means are equal.

Through examination of the interaction as well as each factor, we see that the p-value was not significant for any individual factor, although Case was close with a P-value =0.057. This was may be due to the limited number of samples. However, there does seem to be an effect due to the interaction of the meal bag and the case. As stated earlier, this may be due to a specific menu item and should be investigated further.

Table 28. Weight of Meal Bags of Configuration 1 in grams

Box Specimen	Box Type	Meal Bag Type	Case	Meal	Primary Bag	Secondary Bag	Total Bag Weight
1	Solid	Current	A	1	23.328	7.203	30.531
				2	24.489	6.758	31.247
				3	23.108	7.076	30.184
				4	23.535	7.338	30.873
				5	23.683	6.868	30.551
				6	23.125	7.099	30.224
				7	23.207	6.927	30.134
				8	23.775	7.165	30.94
				9	23.244	7.003	30.247
				10	23.296	6.803	30.099
				11	22.827	6.697	29.524
				12	23.674	6.844	30.518
2	Solid	Current	A	1	23.192	7.317	30.509
				2	24.215	6.742	30.957
				3	23.216	7.227	30.443
				4	23.244	7.156	30.4
				5	22.85	6.778	29.628
				6	23.041	7.059	30.1
				7	23.043	7.064	30.107
				8	23.305	7.011	30.316
				9	23.281	7.095	30.376
				10	23.143	6.7	29.843
				11	23.036	6.848	29.884
				12	23.321	6.852	30.173
3	Solid	Old	B	13	23.38	7.188	30.568
				14	23.532	6.7	30.232
				15	23.356	6.624	29.98
				16	23.237	6.659	29.896
				17	23.708	7.215	30.923
				18	23.427	6.747	30.174
				19	23.295	6.779	30.074
				20	23.128	7.186	30.314
				21	23.79	7.249	31.039
				22	23.349	6.807	30.156
				23	23.737	7.116	30.853
				24	23.232	6.684	29.916

Table 29. Weight of Meal Bags of Configuration 2 in grams

Box Specimen	Box Type	Meal Bag Type	Case	Meal	Primary Bag	Secondary Bag	Total Bag Weight
4	Corrugated	Current	A	1	22.883	7.092	29.975
				2	24.471	6.803	31.274
				3	23.083	7.185	30.268
				4	23.302	7.233	30.535
				5	23.469	6.905	30.374
				6	23.254	6.977	30.231
				7	23.137	7.136	30.273
				8	23.989	7.034	31.023
				9	23.485	7.095	30.58
				10	23.334	6.915	30.249
				11	23.187	6.695	29.882
				12	23.363	6.712	30.075
5	Corrugated	Current	B	13	23.18	-	23.18
				14	23.508	6.727	30.235
				15	24.154	-	24.154
				16	23.128	-	23.128
				17	23.847	7.19	31.037
				18	23.292	-	23.292
				19	24.771	6.957	31.728
				20	23.402	7.23	30.632
				21	22.65	-	22.65
				22	23.488	-	23.488
				23	23.004	7.155	30.159
				24	23.351	6.86	30.211
6	Corrugated	Current	B	13	23.2	7.227	30.427
				14	23.519	6.781	30.3
				15	23.385	6.65	30.035
				16	23.136	6.703	29.839
				17	23.825	7.224	31.049
				18	23.484	6.791	30.275
				19	23.862	6.925	30.787
				20	23.335	7.183	30.518
				21	23.564	7.219	30.783
				22	23.125	6.779	29.904
				23	23.114	7.079	30.193
				24	23.295	6.886	30.181

Some significant observations include:

50% of the meals in Box 5 were missing the clear secondary bags (6 bags missing). These meal bags were not included in the average or other analyses.

One bag in box 8 could not be measured because cocoa had leaked all over the inside of the package.
One bag in box 9 and box 18 could not be measured because peanut butter had leaked all over the inside of the package.

6.1.3 Recommendations

Question 1

The corrugated fiberboard outer box weighs approximately 135 grams less than the solid fiberboard outer box.

Question 2

The ANOVA showed that the Outer box, the Meal Bag, and the Case are not significant as individual factors, but the Meal Bag and Case interaction was significant. Case A was significantly different in weight compared to Case B. Case A was approximately 700 grams less than Case B. While this was statistically significant, the meals in the cases are chosen to meet specific nutritional requirements and cannot be changed at this time.

Question 3

The control assembly of the current meal bag with the solid fiberboard box showed the least number of defects.

The decrease in weight of the overall packaging assembly was approximately 145 grams. When multiplied by the number of MREs supplied to troops globally, this reduction in weight may lead to savings of several million dollars. Furthermore, we preserve the performance of the packaging, ensuring a well-fed warfighter continues to receive meals with limited defects.

6.1.4 Considerations

Due to the limited number of samples tested, it was recommended to perform additional tests to verify the cause of the defects. The ANOVA showed that none of the individual factors were significant when examining the number of defects, however there was an interaction between the case and the meal bag. Furthermore, the EDA of the number of defects by case showed that, at a higher significance level, the number of defects in Case A would be significantly different than Case B. This may be due to a specific menu item or the sample size may be too small to have enough power to detect the significance of the terms. Many of the defects were related to permeation characteristics that are affected by the meal bag material characteristics. Performing the altitude testing and environmental testing on a larger sample may be able to better determine the performance of the meal bag.

6.2 Performance Testing

Glue Performance - The containers and each individual meal bag was opened and examined for any defects or exposure of contents. While each ration item was not specifically opened and inspected, some observations regarding specific items were noted. Only obvious leaks, crushed items, or other defects that could be noticed from opening the meal bag were noted. Desired tastes, textures, smells, or colors were not examined for edibility.

Table 30. Number of Defects Resulting from Performance Testing

Specimen	Box Type	Meal Bag Type	Case	Number of Defects[1]
1	Solid	Current	A	0
2	Solid	Current	B	1
3	Solid	Current	B	0
4	Corrugated	Current	A	1
5	Corrugated	Current	B	2
6	Corrugated	Current	A	1

Some significant observations include:

- The glue that was used for all the boxes worked well on the corrugated box, however it did not perform as well on the solid fiberboard as the previously specified glue. The strapping held the box flaps closed when needed.
- The gum melted in each meal bag and was not considered a defect during the statistical analysis because all containers had the same result.
- Specific meal items that leaked or busted during testing include:

Figure 76. Glue separation on Solid Fiberboard

6.2.1 Compression Testing

During the compression, it was noted that the stress was being concentrated along the edges of the top deck boards of the pallet. In both the standard conditioned and high humidity conditioned samples, the corrugated unitized loads deformed notably more than the solid fiberboard samples. Although the deformation was greater in the corrugated unitized loads, package remained safe for storage and transport. The deformed MRE cases were open and inspected for any rupture of the contents. No damage was observed and the high humidity corrugated and solid fiberboard containers are shown in Figure 77and Figure 78.

Table 31. Compression Testing of Unitized Loads

Sample	Conditions	Test Load	Displacement	Observations During Testing
Corrugated	23°C @ 50% RH	10,395 lbf	~1.7"	At test load, it was observed that the bottom cases of MRE's along the outside edges deformed around the pallet deck boards (see Figure 3-3)
Solid	23°C @ 50% RH	10,395 lbf	~1.2"	At test load , it was observed that the bottom cases of MRE's along the outside edges slightly deformed around the pallet deck boards (see Figure 3-4)
Corrugated	25°C @ 90%RH	10,395 lbf	~3.2"	At test load , it was observed that the bottom cases of MRE's along the outside edges deformed around the pallet deck boards (see Figure 3-5)
Solid	25°C @ 90%RH	10,395 lbf	~2.0"	At test load , it was observed that the bottom cases of MRE's along the outside edges slightly deformed around the pallet deck boards (see Figure 3-6)

Figure 77. Corrugated Fiberboard Case Deformation (High Humidity Conditions)

Figure 78. Solid Fiberboard Case Deformation (High Humidity Conditions)

6.2.2 Impact Recline Results:
During each of the impacts, the unitized load slightly shifted on the pallet. There were no appreciable differences observed between the performance of the corrugated fiberboard cases and the solid fiberboard cases. A list of the observations made during the Inclined Impact testing are listed in Table 32.

Table 32. Incline Impact Test

Sample	Conditions	Observations
Corrugated	23°C @ 50% RH	The unitized load shifted slightly during impact of each edge. No damage was observed.
Solid	23°C @ 50% RH	The unitized load shifted slightly during impact of each edge. No damage was observed.

During each of the impacts, the unitized load shifted on the pallet. The amount of load shift varied on each sample, but all loads remained stable. A list of the observations made for each sample during the Rotational Drop testing are listed in Table 33 and the photos of the pallets after the test are shown in Figure 79, Figure 80, Figure 81, Figure 82, and Figure 83.

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Table 33. Rotational Drop Test

Sample	Conditions	Observations
Corrugated	23°C @ 50% RH	Following each edge drop, the packages shifted slightly on the pallet. Following each corner drop, the packages shifted approximately 3-4" toward the impacted corner. At the completion of the testing (Figure 3-10), the unitized load was stable, and just slightly off center of the pallet
Solid	23°C @ 50% RH	Following each edge drop, the packages shifted slightly on the pallet. Following each corner drop, the packages shifted approximately 3-4" toward the impacted corner. At the completion of the testing (Figure 3-11), the unitized load was stable, and just slightly off center of the pallet
Corrugated	25°C @ 90% RH	Following each edge drop, the packages shifted slightly on the pallet. During the first corner drop, one of the pallet stringers cracked from the end of the stringer into the side fork pocket (Figure 3-14). Following each corner drop, the packages shifted approximately 3-4" toward the impacted corner. On the final corner drop, the cases shifted allowing the cases to hang off the side of the pallet approximately 8" (Figure 3-12). Following the test, the unitized load remained stable on the pallet, and was easily re-centered onto the pallet using a forklift.
Solid	25°C @ 90% RH	Following each edge drop, the packages shifted slightly on the pallet. Following each corner drop, the packages shifted approximately 3-4" toward the impacted corner. At the completion of the testing (Figure 3-13), the unitized load was stable, and just slightly off center of the pallet

Figure 79. Corrugated Fiberboard Unitized Load (Std. Conditions) Following Rotational Drop Tests

Figure 80. Solid Fiberboard Unitized Load (Std. Conditions) Following Rotational Drop Tests

Figure 81. Corrugated Fiberboard Unitized Load (High Humidity Conditions) Following Rotational Drop Tests

Figure 82. Solid Fiberboard Unitized Load (High Humidity Conditions) Following Rotational Drop Tests

Figure 83. Cracked Stringer During Rotational Drop Tests

Although the test results varied slightly between the corrugated fiberboard cases, and the solid fiberboard cases, LOGSA believes that both configurations are capable of both commercial and non-commercial transportation and storage.

6.2.3 Deflection Data from Marengo Caves

The pallets assembled at AmeriQual were stored at the caves with controlled temperature and humidity for one year stacked 4 pallets high. Both the solid fiberboard as a control and the coated corrugated containers were stacked and the deflection was measured each month. Table 34 and Table 35 contain the data for the corrugated containers while Table 36 and Table 37 contain the solid fiberboard data. For both containers, CF1 was the pallet on the bottom and CF4 was the pallet on top. There was not significant amount of deflection for either corrugated or solid fiberboard containers over the year period.

Table 34. Stack 1 Corrugated

Year	Month	Date	Temperature	Relative Humidity	CF1	CF2	CF3	CF4
2013	July	31-Jul	59	67	46.56	46.44	46.44	46.44
2013	August	30-Aug	57	74	46.19	46.19	46.00	46.13
2013	September		57	74	46.18	46.15	45.97	46.10
2013	October		57	74	46.14	46.12	45.95	46.09
2013	November		57	74	46.12	46.00	45.93	46.07
2013	December		57	74	46.10	45.91	45.91	46.05
2014	January		57	74	46.07	45.87	45.90	46.04
2014	February		57	74	46.05	45.69	45.87	46.03
2014	March		57	74	46.03	45.60	45.85	46.02
2014	April		57	74	46.02	45.58	45.82	46.01
2014	May		57	74	46.01	45.53	45.78	46.00
2014	June		57	74	46.00	45.51	45.75	46.00
2014	July	27-Jul	57	71	46.00	45.50	45.75	46.00

Table 35. Stack 2 Corrugated

Year	Month	Date	Temperature	Relative Humidity	CF1	CF2	CF3	CF4
2013	July	31-Jul			46.06	46.13	46.81	46.56
2013	August	30-Aug	57	74	45.69	45.81	46.69	46.38
2013	September		57	74	45.65	45.80	46.68	46.35
2013	October		57	74	45.62	45.76	46.68	46.33
2013	November		57	74	45.59	45.74	46.67	46.32
2013	December		57	74	45.56	45.72	46.65	46.31
2014	January		57	74	45.54	45.68	46.64	46.30
2014	February		57	74	45.52	45.64	46.64	46.28
2014	March		57	74	45.49	45.62	46.63	46.27
2014	April		57	74	45.45	45.58	46.63	46.26
2014	May		57	74	45.42	45.55	46.63	46.25
2014	June		57	74	45.38	45.50	46.63	46.25
2014	July	23-Jul	57	71	45.38	45.50	46.63	46.25

Table 36. Stack 3 Solid Fiber

Year	Month	Date	Temperature	Relative Humidity	SF1	SF2	SF3	SF4
2013	July				45.94	45.81	45.69	45.63
2013	August	30-Aug	57	74	45.69	45.69	45.50	45.50
2013	September		57	74	45.68	45.67	45.48	45.47
2013	October		57	74	45.65	45.65	45.45	45.43
2013	November		57	74	45.63	45.61	45.43	45.42
2013	December		57	74	45.60	45.60	45.40	45.40
2014	January		57	74	45.56	45.56	45.39	45.38
2014	February		57	74	45.54	45.53	45.39	45.34
2014	March		57	74	45.53	45.53	45.38	45.30
2014	April		57	74	45.52	45.52	45.38	45.28
2014	May		57	74	45.51	45.50	45.38	45.25
2014	June		57	74	45.50	45.50	45.38	45.25
2014	July	23-Jul	57	71	45.50	45.50	45.38	45.25

Table 37 .Stack $ Solid Fiberboard.

Year	Month	Date	Temperature	Relative Humidity	SF1	SF2	SF3	SF4
2013	July				45.69	45.75	45.31	45.56
2013	August	30-Aug	57	74	45.63	45.63	45.13	45.56
2013	September		57	74	45.60	45.60	45.10	45.55
2013	October		57	74	45.58	45.58	45.01	45.54
2013	November		57	74	45.52	45.56	44.95	45.52
2013	December		57	74	45.49	45.55	44.96	45.51
2014	January		57	74	45.47	45.54	44.93	45.50
2014	February		57	74	45.43	45.53	44.91	45.50
2014	March		57	74	45.40	45.52	44.90	45.50
2014	April		57	74	45.39	45.52	44.89	45.50
2014	May		57	74	45.38	45.51	44.88	45.50
2014	June		57	74	45.38	45.50	44.88	45.50
2014	July	23-Jul	57	71	45.38	45.50	44.88	45.50

6.3 Repulpability and Recyclability

The coated corrugated samples passed both the repulpability and the recyclability testing which was performed by Western Michigan University, a certified laboratory. The solid fiberboard did not pass the tests due to its delamination of layers. Table 38 gives a summary of the results for the solid fiberboard control and the corrugated container.

Table 38 Summary of the Repuplpability / Recyclability of Sold Fiberboard Control vs Corrugated Fiberboard

Test	Solid Fiberboard Pass or Fail	Coated Corrugated Fiberboard Pass or Fail
Fibre Yield (> 85%)	No	Yes
Operation Impact Acceptability	Yes	Yes
Product Performance	Yes	Yes
Product Appearance /Spot Count Acceptability	Yes	Yes
Overall Pass or Fail	No	Yes

6.4 Biodegradation

Based on the analysis of the four (4) samples indicates that samples A-D are comprised of 100.0% bio based carbon. Sample A was found to be 100.0% bio based. The bio based value does not directly correlate to the amount of potential biodegradation of the sample. Sample B was found to be 100.0% bio based. The bio based value does not directly correlate to the amount of potential biodegradation of the sample. Sample C was found to be 100.0% bio based. The bio based value does not directly correlate to the amount of potential biodegradation of the sample. Sample D was found to be 100.0% bio based. The bio based value does not directly correlate to the amount of potential biodegradation of the sample.

The four (4) samples were evaluated for their mean bio based content by BETA ™ Analytic Inc. in Miami, Florida. In our opinion, based on the overall carbon conversion (mineralization) of the replicates tested, the ASTM D6400 requirements have not been met for Samples A and B. The greater 90% carbon mineralization was not achieved by Samples A and B within one-hundred and eighty (180han) days of compost exposure.

The Positive Cellulose Controls surpassed the 70% carbon conversion requirement in forty-five (45) days per ASTM D5338 Mineralization. Sample A (Spectra-Guard 3003 Coating) has not met the 90% carbon conversion requirement for a biodegradable material per ASTM D6400 within one-hundred and eighty (180) days of compost exposure. Sample B (Lap Adhesive) has not met the 90% carbon conversion requirement for a biodegradable material per ASTM D6400 within one-hundred and eighty (180) days of compost exposure.

The Aerobic Biodegradation per ASTM D5338 @ 58 ± 2 C of the test samples yielded the following in 180 days based on (%) carbon conversion (Also refer to Table 39).

Table 39. Carbon Conversion Based on Carbon Dioxide Production

Sample:	Description	Carbon Conversion (%) Based on CO_2 Production)
	Positive Cellulose Control – 90-180 Day - One (1) Sample **91.35%**	
	Positive Cellulose Control – 90-180 Day - One (1) Sample **88.26%**	
A1.	Spectra-Guard 3003 Coating, Dried, Ground, 0-180 Day	**26.34%**
A2.	Spectra-Guard 3003 Coating, Dried, Ground, 0-180 Day	**41.62%**
A3.	Spectra-Guard 3003 Coating, Dried, Ground, 0-180 Day	**56.78%**
B1.	York Lap Adhesive, Dried, Ground, 0-180 Day	**19.45%**
B2.	York Lap Adhesive, Dried, Ground, 0-180 Day	**47.51%**
B3.	York Lap Adhesive, Dried, Ground, 0-180 Day	**25.08%**

The test samples Biodegradation % (normalized for cellulose) in the 180 day compost exposure (Refer to Table 40).

Table 40. Normalized % Biodegradation Based on Carbon Dioxide Production

Sample ID	Normalized % Biodegradation
Positive Cellulose Control	100%
A1. Spectra-Guard 3003	29.33%
A2. Spectra-Guard 3003	46.34%
A3. Spectra-Guard 3003	63.22%
B1. York Lap Adhesive	21.66%
B2. York Lap Adhesive	52.90%
B3. York Lap Adhesive	27.93%

Note: All samples were dried and Ground Experiment Time 0-180 days

The evaluation of the samples was run per ASTM D5338 at 58 ± 2 °C per the Tier Two Level testing per ASTM D6400. Sample weights of approximately 50.0 g were placed into roughly 300 g of dry composting material. The composting material was prepared by AMC, Inc. following the recipe noted in ISO 20200. The composting medium had a Carbon: Nitrogen ratio of 29:1, which was within the specifications for this test. The pH of the compost material was 7.0 with a total dry solids percentage of 50% when dried at 105C until constant weight was achieved and was within the 50%-55% range. The volatile solids had a dry matter content of 30% which was under the 70% allowed. A Wiley Mill was used to prepare the Positive Cellulose Controls and Samples A-B. Dry, ground cellulose material was placed into Flask 2 for exposure. Dry, ground Coating and Adhesive samples were placed into flasks for exposure. The test samples degraded in the compost material for 180 days.

The cellulose controls had total degradation. The carbon conversion (%) for the cellulose controls were normal for this test and also confirmed a viable, active compost mixture. The carbon conversion values surpassed the 70.0% requirement for this type of material. The amount of carbon from the 0-90 Day Positive Cellulose Control converted to CO_2 during the test was 91.35% and the 90-180 Day Positive Cellulose Control converted 88.26% of the total carbon present in the sample. The amount of carbon from samples A1-A3 (Spectra-Guard 3003 Coating, Dried, Ground) converted to CO_2 during the test had an average of 41.58% of the total carbon present in the sample over the 180 day compost exposure. The amount of carbon from samples B1-B3 (York Lap Adhesive, Dried, Ground) converted to CO_2 during the test had an average of 30.68% of the total carbon present in the sample over the 180 day compost exposure. The % biodgradation of the cellulose was 100.00% since the entire sample had degraded. This was the reference standard for calculating the % Biodegradation of the Coating and Adhesive samples. Since the cellulose controls produced an average of 89.81% C to CO_2, the samples values were compared to this number. The % Biodegradation of Samples A1-A3 compared to the positive cellulose controls had an average of 46.30% over the 180- day compost exposure. The % Biodegradation of Samples B1-B3 compared to the positive cellulose controls had an average of 34.16% over the 180- day compost exposure. The % C to CO_2 of the Coating and Adhesive samples were compared to the average % C to CO_2 of the positive cellulose controls. Based on the 180-day carbon conversion, the Spectra Guard 3003 Coating and York Lap Adhesive did not meet the ASTM D5338/ASTM D6400 requirements for a biodegradable material. Table 41 shows the data for biodegradation in compost for samples A and B. Table 42 depicts the conversion and the efficiency calculations for the samples. Figure 84 shows the data in graphical form for sample B for before and after normalization of the data.

Table 41. ASTM D5338 Aerobic Biodegradation - 180 Day Compost Exposure

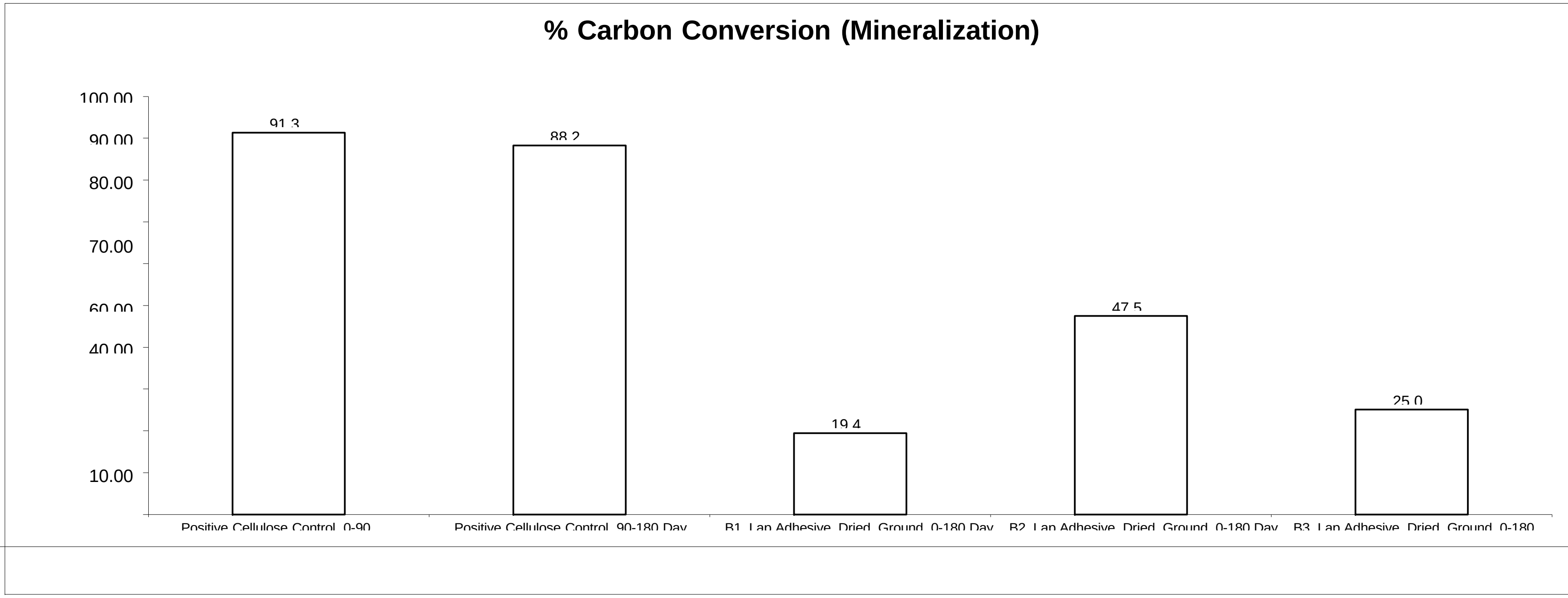
Sample ID	Sample Reference	Sample Size	Initial Weight (g)	Final Weight (g)	% Weight Loss	% Carbon	Flask Number
Blank 1	0-90 Day Standard Compost	1700 mL	NA	NA	NA	NA	**1**
Blank 1B	90-180 Day Standard Compost	900 mL was added to exwasting amount	NA	NA	NA	NA	**1B**
Blank 2	0-90 Day Positive Cellulose Control	Dry Material - Ground	50.9512	NA	NA	41.74	**2**
Blank 2B	90-180 Day Positive Cellulose Control	Dry Material - Ground	24.5037	NA	NA	41.74	**2B**
A1	SpectraGuard Coating	Dry Material - Ground	50.0075	NA	NA	44.13	**3**
A2	SpectraGuard Coating	Dry Material - Ground	50.1457	NA	NA	44.13	**4**
A3	SpectraGuard Coating	Dry Material - Ground	50.4009	NA	NA	44.13	**5**
B1	York Lap Adhesive	Dry Material - Ground	50.1340	NA	NA	59.83	**6**
B2	York Lap Adhesive	Dry Material - Ground	50.2156	NA	NA	59.83	**7**
B3	York Lap Adhesive	Dry Material - Ground	50.0985	NA	NA	59.83	**8**

Table 42. Conversion and Efficiency Calculations

	1	1B	2	2B	3	4	5	6	7	8
Sample Reference	**0-90 Day Standard Compost Blank 1**	**90-180 Day Standard Compost Blank 1B**	**0-90 Day Cellulose Control Blank 2**	**90-180 Day Cellulose Control Blank 2B**	**0-180 Day Spectra Guard Coating #1**	**0-180 Day Spectra Guard Coating #2**	**0-180 Day Spectra Guard Coating #3**	**0-180 Day York Lap Adhesive #1**	**0-180 Day York Lap Adhesive #2**	**0-180 Day York Lap Adhesive #3**
Galbraith Carbon %:	NA	NA	41.74	41.74	44.13	44.13	44.13	59.83	59.83	59.83
Initial Weight (g):	NA	NA	50.9512	24.5037	50.0075	50.1457	50.4009	50.1340	50.2156	50.0985
Final Weight (g):	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Actual Total CO2 (mg):	172384.00	88616.00	243573.00	121696.00	282301.21	294750.49	307274.00	282377.20	313301.00	288551.24
Compost Corrected Total CO2 (mg):	NA	NA	71189.00	33080.00	21301.21	33750.49	46274.00	21377.20	52301.00	27551.24
Priming Effect Corrected CO2 (mg):	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Initial Weight (g):	NA	NA	50.9512	24.5037	50.0075	50.1457	50.4009	50.1340	50.2156	50.0985
Carbon Fraction:	NA	NA	0.4174	0.4174	0.4413	0.4413	0.4413	0.5983	0.5983	0.5983
Available Grams C:	NA	NA	21.2670	10.2278	22.0683	22.1293	22.2419	29.9952	30.0440	29.9739
Theoretical CO2 (g):	NA	NA	77.9298	37.4784	80.8659	81.0894	81.5021	109.9127	110.0916	109.8349
% C to CO2:* **	NA	NA	91.35	88.26	26.34	41.62	56.78	19.45	47.51	25.08
Priming Effect Corrected % C to CO2:*	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Actual Weight Loss (g):	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Carbon Fraction:	NA	NA	0.4174	0.4174	0.4413	0.4413	0.4413	0.5983	0.5983	0.5983
Related Available Grams C:	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Max.Theo.Available CO2 (g):**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
% Biodegradation (Normalized)******	NA	NA	100.00	100.00	29.33	46.34	63.22	21.66	52.90	27.93

**** All samples were normalized by using the average carbon conversion (89.81%) of each cellulose blank.
*** This refers to amount of carbon in sample actually converted to carbon dioxide.
** This refers to amount of carbon in weight loss that appears as carbon dioxide.
*% C to CO2 correct ed for Priming Effect

a)



b)

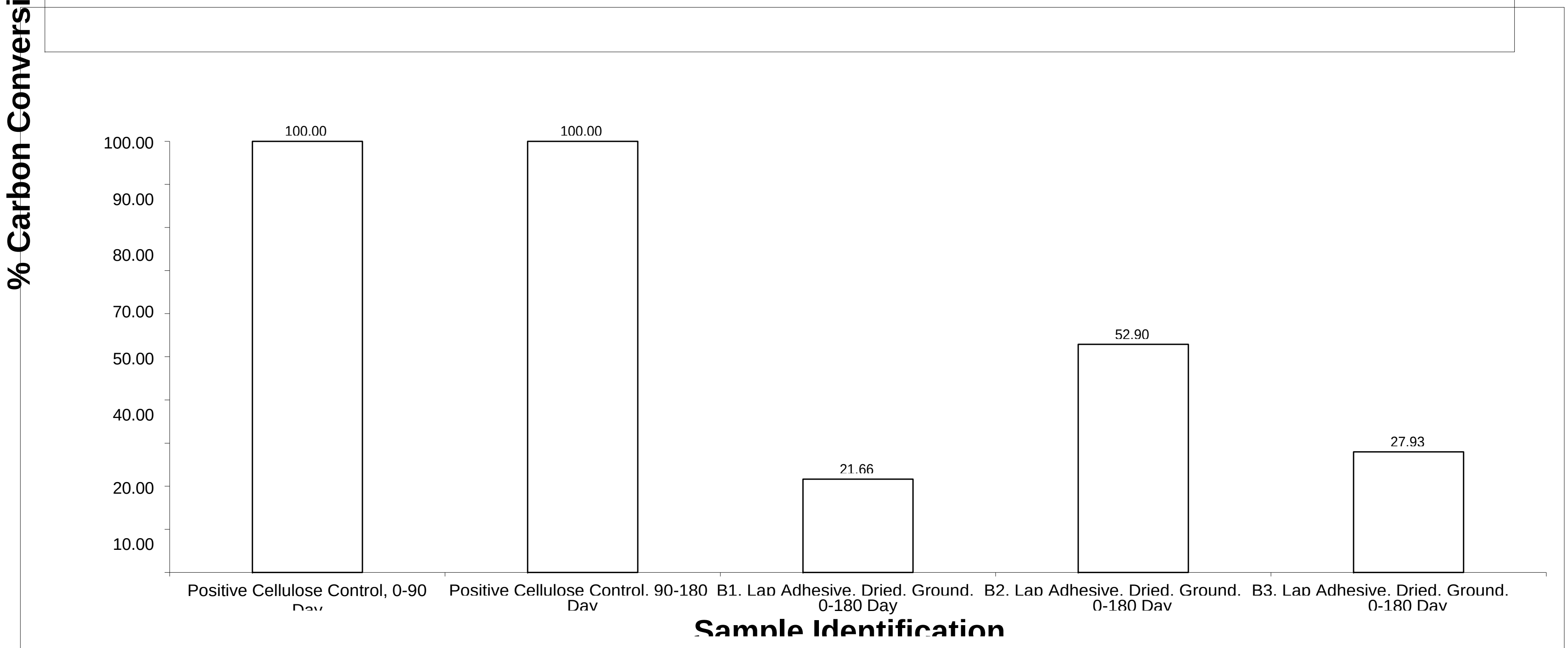


Figure 84. ASTM D5338 – 180-Day Compost Exposure a) before and b) after normalization to cellulose.

6.5 Insect Infestation

Insect infestation studies were done on small pieces of fiberboard cut in 4 x 4 inch samples and containers. There was no penetration when there were the small samples cut out from the corrugated or solid fiberboard containers. Insect penetration was recorded for the case samples and shown below in Table 43.

Table 43. Total Insect observed by Case

	Corrugate				Fiber Board		
	RFB	CB	IMM		RFB	CB	IMM
1	11	162	11	**1**	0	0	0
2	19	109	2	**2**	0	0	0
3	32	39	19	**3**	0	0	0
4	78	63	0	**4**	0	0	0
5	34	111	27	**5**	8	24	0
6	101	18	20	**6**	0	0	0
7	92	92	18	**7**	0	0	0
8	14	64	3	**8**	0	0	0
9	56	33	8	**9**	0	0	0
10	29	28	0	**10**	0	0	0
11	64	83	32	**11**	0	0	0
12	55	40	9	**12**	0	0	0
13	23	23	2	**13**	0	0	0
14	3	72	1	**14**	0	0	0
15	64	62	1	**15**	0	2	0
16	85	92	12	**16**	0	0	0
17	153	128	34	**17**	0	0	0
18	28	29	2	**18**	0	0	0
19	95	63	0	**19**	0	0	0
20	48	48	0	**20**	0	0	0
21	64	59	9	**21**	0	0	0
22	29	62	2	**22**	0	0	0
23	36	37	0	**23**	0	0	0
24	16	48	3	**24**	0	0	0
25	105	28	1	**25**	0	0	0

The corrugate cases have no barrier to impede insect entry into the meal bag case. The fiber board's rigidity, solid core and glue patterns provide a primary barrier to insect invasion. The fluting of corrugate material also acts a harborage for stored-product insects like the red flour beetle and a secure pupation site for Indian meal moths. However the primary, secondary and tertiary packaging for the individual meal bags provides substantial resistance to insect invasion or penetration. None of the individual meal bags in either the corrugate or fiber board cases showed evidence of infestation.

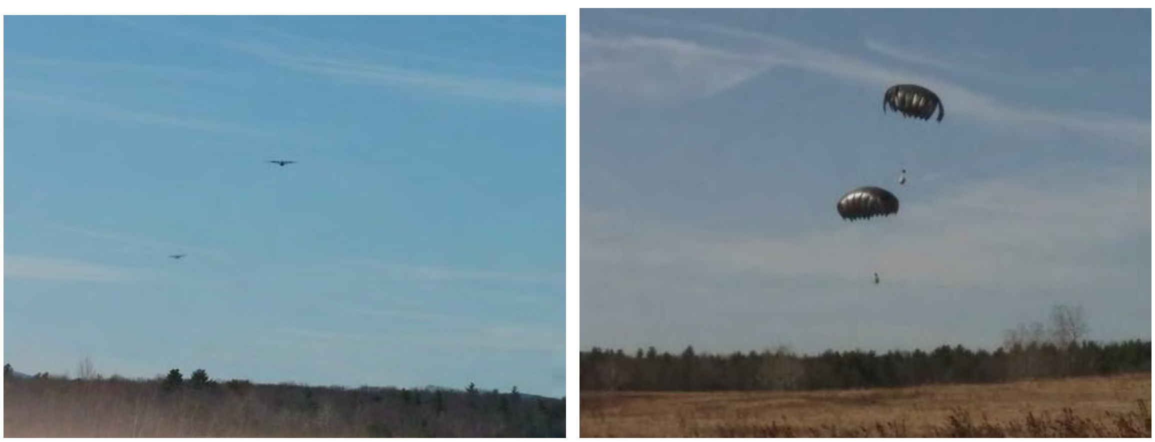
Figure 85. Fiberboard during infestation study (left) solid fiberboard (right) corrugated.

6.6 Aerial Delivery

This test report documents findings from the Meals Ready-to-Eat (MRE) corrugated fiberboard container test conducted at Yuma Test Center (YTC), from 27 July to 7 August 2015. It must not be construed as the United States (U.S.) Army Test and Evaluation Command (ATEC) system evaluation report or system assessment for the fiberboard container.

a) b)

Figure 86. Rigging the corrugated pallets a) Before and b) after.



a) b)

Figure 87. Dropping the ration a) before release and b) after release.

6.6.1 MRE 33 Case Damage data 2015

There were four pallets dropped as part of the experiment, two utilizing corrugated fiber board cases and two utilizing a solid board. Each pallet contained 50 cases, five rows of ten cases each, although two of those cases contained wooden boxes (some boxes contained accelerometers). The list of damage types was determined by one of the project leads for the data collection.

Table 44 shows the damage breakdown by pallet and by layer numbers in the main body of the table are quantities of recorded damage "incidents" per layer for a given pallet, the fifth layer always being at the top of the pallet and the first layer being the bottom layer. Each layer contains ten cases, each of which can (and usually do) have multiple types of damage. The bottom of the table contains two summary rows, the first labeled "Total" which sums the recorded damage incidents in each layer, and "Percentage" which provides a percentage breakdown of damage incidents per layer of a pallet. There are also four columns at the right end of the table that sum across layers for each type of damage, this provides total quantities of damage incidents per damage type for a given pallet.
Table 45 shows the total case damage for corrugated and solid board pallets
This table provides a higher level summary of the data. This table sums together damage incident quantities for both corrugated pallets and both solid board pallets. The table contains the same layer total and percentage rows contained in Table Table 45, but includes total damage incident quantities for both corrugated and both solid board case pallets along with percentage breakdowns based on those quantities. As an important note, although the table contains location and type columns at the beginning of the table highlighted in green, these are not used for any of the table's calculations, their purpose was to populate the table.

Table 46 shows the total incidents of case damage by location on case by layer.
This table was very similar to

Table 44, only difference was that the damage numbers summed based on the "Location" column listed in

Table 44. These designations can be changed and updated in the highlighted green area of that table, the updates propagate through the table after a manual refresh.

Table 47 displays the total incidents of case damage by damage type by layer for corrugated and solid board pallets. This table was very similar to **Table 46**, only difference was that the damage numbers summed based on the "Type" column listed in **Table 46**. These designations can be changed and updated in the highlighted green area of that table, the updates propagate through the table after a manual refresh.

Table 44. Damage Breakdown by Pallet and by Layer

	Top		Corrugated		Bottom	Top		Corrugated		Bottom	Top		Solid		Bottom	Top		Solid		Bottom	Corr.	Corr.	Solid	Solid
Pallet	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	1	2	3	4
Layer	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	Total	Total	Total	Total
Data Recorded																								
abrasions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
accelerometer	0	0	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	2	0	0	2	2	2	2
bottom crush	0	0	2	5	7	5	5	2	5	7	0	1	5	9	6	2	2	5	9	5	14	24	21	23
bottom dent	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
bottom flap delamination	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
bottom flap tear	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
corner crush	5	2	3	2	4	7	3	1	2	0	6	2	1	1	3	6	1	1	0	2	16	13	13	10
corner tear	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1	1
edge corner crush	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
edge crush	4	8	6	9	7	9	9	8	8	10	5	4	2	3	3	7	4	3	5	9	34	44	17	28
edge liner tear	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	3	0	0
edge scuff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
edge tear	0	0	0	1	3	0	0	1	1	5	0	0	0	0	0	1	0	0	0	0	4	7	0	1
edge tear through liner	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
edge tear with inner liner tear	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
end crush	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	2	1	0	2	0	4
end tear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
flap crush	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
flap puncture	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
flap tear	4	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0
general crush	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
general tear	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
large whole on side due to tear	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
liner edge tear	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
liner tear	0	0	0	0	0	0	0	1	4	0	0	0	0	3	1	0	1	1	4	3	0	5	4	9
manufacturer's join unglued	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
manufacturer's joint delaminat	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5	0	0
manufacturer's joint half rippe	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
manufacturer's joint tear	0	0	0	3	7	0	1	2	2	1	0	0	0	0	0	0	0	0	0	0	10	6	0	0
manufacturer's seal tear	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
none	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	1	0	0	0	0	0	0	4	1
side crush	0	1	6	6	8	2	0	2	8	7	0	0	0	0	0	0	0	0	0	2	21	19	0	2
side dent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
side edge tear	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
side liner tear	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
side puncture	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	3
side tear	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	1	1	0
side wall liner tear	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	2	0	0
side wall tear	0	0	0	1	5	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	6	1	0	1
top crush	0	2	0	0	0	1	4	2	1	5	1	3	6	5	10	0	2	7	9	10	2	13	25	28
Total	16	16	22	30	48	32	23	23	33	48	16	13	18	21	23	23	14	19	29	32	132	159	91	117
Percentage	12.1%	12.1%	16.7%	22.7%	36.4%	20.1%	14.5%	14.5%	20.8%	30.2%	17.6%	14.3%	19.8%	23.1%	25.3%	19.7%	12.0%	16.2%	24.8%	27.4%				

Table 45. Total Case Damage for Corrugated and Solid Board Pallets

			Top		Corrugated (1 and 2)		Bottom	Top		Solid (3 and 4)		Bottom	Corrugated	Solid	Corrugated	Solid
		Layer	5	4	3	2	1	5	4	3	2	1	Total	Total	%	%
Damage	Location	Type														
abrasions	not specific	abrasion	0	0	0	0	0	0	1	0	0	0	0	1	0.0%	0.5%
accelerometer	N/A	N/A	0	0	4	0	0	0	0	4	0	0	4	4	1.4%	1.9%
bottom crush	bottom	crush	5	5	4	10	14	2	3	10	18	11	38	44	13.1%	21.2%
bottom dent	bottom	dent	1	0	0	0	0	0	0	0	0	0	1	0	0.3%	0.0%
bottom flap delamination	bottom	delamination	1	0	1	0	0	0	0	0	0	0	2	0	0.7%	0.0%
bottom flap tear	bottom	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
corner crush	corner	crush	12	5	4	4	4	12	3	2	1	5	29	23	10.0%	11.1%
corner tear	corner	tear	0	0	0	1	0	2	0	0	0	0	1	2	0.3%	1.0%
edge corner crush	edge	crush	0	0	0	0	0	1	0	0	0	0	0	1	0.0%	0.5%
edge crush	edge	crush	13	17	14	17	17	12	8	5	8	12	78	45	26.8%	21.6%
edge liner tear	edge	tear	1	0	1	0	2	0	0	0	0	0	4	0	1.4%	0.0%
edge scuff	edge	abrasion	0	0	0	0	0	1	0	0	0	0	0	1	0.0%	0.5%
edge tear	edge	tear	0	0	1	2	8	1	0	0	0	0	11	1	3.8%	0.5%
edge tear through liner	edge	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
edge tear with inner liner tear	edge	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
end crush	end	crush	0	0	0	1	1	0	1	0	2	1	2	4	0.7%	1.9%
end tear	end	tear	0	0	0	0	0	0	1	0	0	0	0	1	0.0%	0.5%
flap crush	flap	crush	1	0	0	0	0	0	0	0	0	0	1	0	0.3%	0.0%
flap puncture	flap	puncture	1	0	0	0	0	0	1	0	0	0	1	1	0.3%	0.5%
flap tear	flap	tear	9	0	0	0	1	0	0	0	0	0	10	0	3.4%	0.0%
general crush	not specific	crush	0	1	1	0	1	0	0	0	0	0	3	0	1.0%	0.0%
general tear	not specific	tear	0	1	0	0	0	0	0	0	0	0	1	0	0.3%	0.0%
large whole on side due to tear	side	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
liner edge tear	not specific	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
liner tear	not specific	tear	0	0	1	4	0	0	1	1	7	4	5	13	1.7%	6.3%
manufacturer's join unglued	manufacturer's joint	unglued	0	0	1	0	0	0	0	0	0	0	1	0	0.3%	0.0%
manufacturer's joint delaminat	manufacturer's joint	delamination	0	0	0	0	5	0	0	0	0	0	5	0	1.7%	0.0%
manufacturer's joint half rippe	manufacturer's joint	tear	0	0	1	0	0	0	0	0	0	0	1	0	0.3%	0.0%
manufacturer's joint tear	manufacturer's joint	tear	0	1	2	5	8	0	0	0	0	0	16	0	5.5%	0.0%
manufacturer's seal tear	manufacturer's joint	tear	0	0	0	0	0	0	0	1	0	0	0	1	0.0%	0.5%
none	N/A	N/A	0	0	0	0	0	2	2	1	0	0	0	5	0.0%	2.4%
side crush	side	crush	2	1	8	14	15	0	0	0	0	2	40	2	13.7%	1.0%
side dent	side	dent	0	0	0	0	0	0	1	0	0	0	0	1	0.0%	0.5%
side edge tear	side	tear	0	1	0	1	0	0	0	0	0	0	2	0	0.7%	0.0%
side liner tear	side	tear	0	0	0	0	1	0	0	0	0	0	1	0	0.3%	0.0%
side puncture	side	puncture	1	0	0	0	0	3	0	0	0	0	1	3	0.3%	1.4%
side tear	side	tear	0	1	0	1	1	1	0	0	0	0	3	1	1.0%	0.5%
side wall liner tear	side	tear	0	0	0	0	3	0	0	0	0	0	3	0	1.0%	0.0%
side wall tear	side	tear	0	0	0	2	5	1	0	0	0	0	7	1	2.4%	0.5%
top crush	top	crush	1	6	2	1	5	1	5	13	14	20	15	53	5.2%	25.5%
		Total	48	39	45	63	96	39	27	37	50	55	291	208	1	1
		Percentage	16.5%	13.4%	15.5%	21.6%	33.0%	18.8%	13.0%	17.8%	24.0%	26.4%				

Table 46. Total Incidents of Case Damage by Location on Case by Layer

	Top		Corrugated		Bottom	Top		Solid		Bottom	Corrigated	Solid	Corrigated	Solid
Layer	5	4	3	2	1	5	4	3	2	1	Total	Total	%	%
Location														
bottom	7	5	5	10	15	2	3	10	18	11	42	44	14.4%	21.2%
corner	12	5	4	5	4	14	3	2	1	5	30	25	10.3%	12.0%
edge	14	17	16	19	29	15	8	5	8	12	95	48	32.6%	23.1%
end	0	0	0	1	1	0	2	0	2	1	2	5	0.7%	2.4%
flap	11	0	0	0	1	0	1	0	0	0	12	1	4.1%	0.5%
manufacturer's joint	0	1	4	5	13	0	0	1	0	0	23	1	7.9%	0.5%
N/A	0	0	4	0	0	2	2	5	0	0	4	9	1.4%	4.3%
not specific	0	2	2	4	2	0	2	1	7	4	10	14	3.4%	6.7%
side	3	3	8	18	26	5	1	0	0	2	58	8	19.9%	3.8%
top	1	6	2	1	5	1	5	13	14	20	15	53	5.2%	25.5%

Table 47 Total Incidents of Case Damage by Damage Type by Layer for Corrugated and Solid Board Pall

	Top		Corrugated		Bottom	Top		Solid		Bottom	Corrigated	Solid	Corrigated	Solid
Layer	5	4	3	2	1	5	4	3	2	1	Total	Total	%	%
Type														
abrasion	0	0	0	0	0	1	1	0	0	0	0	2	0.0%	1.0%
crush	34	35	33	47	57	28	20	30	43	51	206	172	70.8%	82.7%
delamination	1	0	1	0	5	0	0	0	0	0	7	0	2.4%	0.0%
dent	1	0	0	0	0	0	1	0	0	0	1	1	0.3%	0.5%
N/A	0	0	4	0	0	2	2	5	0	0	4	9	1.4%	4.3%
puncture	2	0	0	0	0	3	1	0	0	0	2	4	0.7%	1.9%
tear	10	4	6	16	34	5	2	2	7	4	70	20	24.1%	9.6%
unglued	0	0	1	0	0	0	0	0	0	0	1	0	0.3%	0.0%

6.6.2 MRE 33 Component Damage 2015

The “Basic Summary” tab contains a full summary of meal component damage from the 2015 air drop data collection exercise for MRE 33 rations. The “Food vs. Non-food” tab contains a table defining which menu items are considered food items and which are considered non-food, in general the distinction was whatever a solider consumes aside from what’s contained in the accessory packet was considered food, everything else was non-food.

See the MRE 33 Case Damage 2015 description for more generalized information on the air drop experiment.

Table 48. Menu Damage Summary for Corrugated Board Case Pallets

Load	Condition	Total Meals	# Meals with Recorded Damage	# Meals with No Damage	# Meals with Food Damage	# Meals with Non-food Damage	# Meals with Both	Overall Food and Non-food Survivability	Food Survivability
Drop 1	Intact	576	31	545	27	4	0	94.6%	95.3%
Drop 2	Intact	576	32	544	30	2	0	94.4%	94.8%
Average		576	31.5	544.5	28.5	3	0	94.5%	95.1%

Table 49: Menu Damage Summary for Solid Board Case Pallets

Load	Condition	Total Meals	# Meals with Recorded Damage	# Meals with No Damage	# Meals with Food Damage	# Meals with Non-food Damage	# Meals with Both	Overall Food and Non-food Survivability	Food Survivability
Drop 3	Intact	576	17	559	17	0	0	97.0%	97.0%
Drop 4	Intact	576	27	549	24	4	1	95.3%	95.8%
Average		576	22	554	20.5	2	0.5	96.2%	96.4%

Table 48 and Table 49 contain menu damage quantity data, this counts the number of menu bags per pallet that contain at least one damaged item. There are a few different designations made between different types of menu items, whether food, non-food, and combined and "survivability" rates based on damage to any item as well as food-only.

Table 50 and Table 51 contain meal component damage quantities, meal components are defined as the individually packaged meal items contained within each meal bag as well as the meal bag itself. So for example, the meal accessory bag may contain a number of items but was considered to be one single item. The data summary provides total quantities, damaged quantities, and survivability rates for all meal components as well as only food components.

Table 50. Meal Component Damage Summary for Corrugated Board Case Pallets

Load	Condition	Total Components	Total Food Components	# Damaged Components	# Components with No Damage	# Food Components with Damage	# Food Components with No Damage	# Non-food Components with Damage	Overall Food and Non-food Survivability	Food Survivability
Drop 1	Intact	6898	4242	33	6865	29	4213	4	99.5%	99.3%
Drop 2	Intact	6878	4254	33	6845	31	4223	2	99.5%	99.3%
Average		6888	4248	33	6855	30	4218	3	99.5%	99.3%

Table 51. Meal Component Damage Summary for Solid Board Case Pallets

Load	Condition	Total Components	Total Food Components	# Damaged Components	# Components with No Damage	# Food Components with Damage	# Food Components with No Damage	# Non-food Components with Damage	Overall Food and Non-food Survivability	Food Survivability
Drop 1	Intact	6893	4245	19	6874	19	4226	0	99.7%	99.6%
Drop 2	Intact	6888	4248	29	6859	25	4223	4	99.6%	99.4%
Average		6890.5	4246.5	24	6866.5	22	4224.5	2	99.7%	99.5%

Table 52 and Table 53 provide layer by layer breakdowns of different damage types for each drop.

Table 54 provides a complete summary of meal component damage regardless of item type.

Table 52. Menu Component Damage Breakdown by Pallet and By Layer

Table 5: Menu Component Damage Breakdown by Pallet and By Layer																								
	Top		Corrugated		Bottom	Top		Corrugated		Bottom	Top		Solid		Bottom	Top		Solid		Bottom	Corr.	Corr.	Solid	Solid
Pallet	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	1	2	3	4
Layer	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	Total	Total	Total	Total
Damage Recorded																								
bottom seal blown	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
corner puncture	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
end seal blown	0	0	0	1	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	2	0	0
pinhole puncture	0	0	0	0	3	0	0	0	1	2	0	0	0	1	2	0	0	0	0	0	3	3	3	0
puncture	0	0	1	4	1	0	1	1	0	0	0	0	0	0	0	2	1	0	0	1	6	2	0	4
puncture in middle	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
ruptured	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
side puncture	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
side seal blown	0	0	0	7	9	0	0	4	7	6	0	0	1	3	9	0	0	1	11	10	16	17	13	22
side seal puncture	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
side tear	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
tear	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
top seal blown	0	0	0	1	2	0	0	0	1	4	0	0	0	0	1	0	0	0	0	1	3	5	1	1
Total	0	0	1	13	19	0	2	5	11	15	0	1	1	5	12	4	1	1	11	12	33	33	19	29
Percentage	0.0%	0.0%	3.0%	39.4%	57.6%	0.0%	6.1%	15.2%	33.3%	45.5%	0.0%	5.3%	5.3%	26.3%	63.2%	13.8%	3.4%	3.4%	37.9%	41.4%				
																					33	33	19	29

Table 53. Menu Food Component Damage Breakdown by Pallet and By Layer

	Top		Corrugated		Bottom	Top		Corrugated		Bottom	Top		Solid		Bottom	Top		Solid		Bottom	Corr.	Corr.	Solid	Solid
Pallet	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	1	2	3	4
Layer	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	Total	Total	Total	Total
Damage Recorded																								
bottom seal blown	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
corner puncture	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
end seal blown	0	0	0	1	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	2	0	0
pinhole puncture	0	0	0	0	3	0	0	0	1	2	0	0	0	1	2	0	0	0	0	0	3	3	3	0
puncture	0	0	1	4	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	5	2	0	1
puncture in middle	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
ruptured	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
side puncture	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
side seal blown	0	0	0	7	9	0	0	4	7	6	0	0	1	3	9	0	0	1	11	10	16	17	13	22
side seal puncture	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
side tear	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
tear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
top seal blown	0	0	0	1	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	1	1	3	1	1
Total	0	0	1	13	15	0	2	5	11	13	0	1	1	5	12	1	0	1	11	12	29	31	19	25
Percentage	0.0%	0.0%	3.4%	44.8%	51.7%	0.0%	6.5%	16.1%	35.5%	41.9%	0.0%	5.3%	5.3%	26.3%	63.2%	4.0%	0.0%	4.0%	44.0%	48.0%				

Table 54. Menu Non-food Component Damage Breakdown by Pallet and By Layer

	Top		Corrugated		Bottom	Top		Corrugated		Bottom	Top		Solid		Bottom	Top		Solid		Bottom	Corr.	Corr.	Solid	Solid
Pallet	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	1	2	3	4
Layer	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1	Total	Total	Total	Total
Damage Recorded																								
bottom seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
corner puncture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
end seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pinhole puncture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
puncture	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	3
puncture in middle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ruptured	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
side puncture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
side seal blown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
side seal puncture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
side tear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tear	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
top seal blown	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	0	0
Total	0	0	0	0	4	0	0	0	0	2	0	0	0	0	0	3	1	0	0	0	4	2	0	4
Percentage	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	75.0%	25.0%	0.0%	0.0%	0.0%				

6.7 Distribution / Transportation

Travel to Alaska to support the study was conducted between the days of 10 February, 2015 and 13 February, 2015. Inspections began on 11 February, 2015 and were completed on 12 February, 2015. A visual inspection was conducted on the 6 pallets being shipped forward to the next location: Yakima, WA. The pallets to be shipped were determined to be Numbers 1, 2, 3, 4, 6, and 8. Pallet #7 was damaged by a forklift and was decided to be broken down and fully inspected, as it was in the worst condition compared to the remaining three test pallets. Pallet #5 was decided to be fully inspected because it was stored stacked on the bottom (another pallet was above it) while in Alaska and seemed to be in marginally lower condition overall than the other control pallet stacked on the bottom.

Visual inspections results shown in Table 55 were of six pallets which took approximately 2 hours to complete. There are far more observable defects in the corrugated fiberboard boxes, many of which are smudged ink.

Table 55. Defects on containers

Pallet Number	Defects Listed	Defects Count	Boxes w/ Defects
All CF Boxes	**B, C, I1, I2, J, L,**	**71**	**59**
1	B, I1, C, L, O	22	20
2	I1, I2, J, C	25	21
8	B, I1, J,	24	18
All SF Boxes	**I2, J, L, O**	**10**	**9**

3	I2, L	4	4
4	I2, J, O	5	4
6	I2,	1	1

With the completion of the visual inspection, the full inspection could begin on the two pallets which were not shipped to Yakima, WA. A box of Menu A and a box of Menu B were provided from both pallets to a food inspector to conduct her own inspection. Three boxes from each pallet were not inspected and were sent to LOGSA Tobyhanna via FedEx for additional testing. Each box was individually labeled for its location, taken off the pallet to a working surface, inspected for outside damage, and then finally torn open to the component level for inspection of the MRE packaging. Inspectors were looking for leaking, premature opening at tears, bursts at seams, and any other possible defects. The overall results of the inspection can be found in Table 56. Inspection started with Pallet #5 on the first day, and by the end of the day, 18 boxes of the 48 total remained uninspected. The second day of inspection began with Pallet #7. An Air Force detail comprised of four airmen was provided to aid with the inspection task. On this day, pallet #7 was completed, work continued on Pallet #5, and subsequently, inspection of the remaining boxes on Pallet #5 was completed in the allotted time. Inspected MREs were disposed of as it was seen fit by the TISA personnel.

Table 56. Full Inspection Break Down Summary

Pallet #	Boxes w/ Defects	MRE "Damage"	Overlap
7 CF	39	11	9
5 SF	7	5	2

MRE damage which was observed was very minor and did not occur on any occasion in the main meal pouches. On only one occasion a side meal pouch, Au Gratin Potatoes, showed some food on the outside of the packaging but inside of the fiberboard sleeve. Peanut Butter, and various beverages were found to have issues most often.

Shipping of the six boxes to Tobyhanna was completed on 11 February, 2015. A FedEx truck picked up the unopened cases directly on the base at the warehouse, and all six packages were successfully delivered to Tobyhanna on 14 February, 2015. Pickup of the 6 visually inspected pallets was completed on 12 February, 2015 via the trucking company Roadway Express. The six pallets were loaded onto the truck and are currently en route to Yakima, WA. The location of the delivery was being tracked each day to prepare to meet them once they arrive for another follow-up visual inspection.

Summary/Conclusions

None of the damage to the food packaging components appeared to be caused by the defects in the fiberboard packaging, but there appeared to be double the occurrences of MRE damage in the CF boxes. Whether this was correlative was determined following the rest of the study. All of the CF boxes showed adhesive failure in that the glue was not making a good bond with the box – a new adhesive or adhesive technique needs to be found.

Travel to Yakima, WA to support the ESTCP study was conducted between the days of 2 March, 2015 and 4 March, 2015. Inspections began early on 3 March, 2015 and were completed later on that same day. Only a visual inspection was conducted on all 6 pallets which had arrived earlier in the month. There did not appear to be any further transportation related damage as compared to what was seen when the pallets left Alaska. When the visual inspection was completed, the pallets were stacked two high in the warehouse. A “dummy” pallet, which was just a non-test pallet found in the warehouse, was used as weight for two of the pallets to simulate stacked storage.

The visual inspections began once they were unstacked and arranged on the floor by the TISA forklift operator at the warehouse and took approximately 2 hours to complete. The results of the inspection can be found in Table 57. There are far more observable defects in the corrugated boxes than in the solid fiberboard.

Table 57. Defects on containers in Yakima

Pallet Number	Defects Listed	Defects Count	Boxes w/ Defects
All CF Boxes	**B, C, F, I1, I2, J**	**82**	**64**
1	B, C, F, I1	26	20
2	B, C, I1, I2, J	28	21
8	B, C, I1, J	28	23
All SF Boxes	**C, G, I1, I2, J, O**	**40**	**31**
3	C, G, I1, I2	12	7
4	G, I2, J, O	10	10
6	C, I1, I2, J, O	18	14

There are a number of changes to this data from previous trips. Originally, in storage in Marengo, IN, only 17 defects were present on the three pallets of Solid Fiberboard boxes which arrived in Washington. Once in WA, it was observed that now 40 defects occupy those same three pallets. As this number has clearly more than doubled, transportation of the containers was possibly a threat to the internal MREs. The pallets of Corrugated Fiberboard boxes displayed 82 defects, which now was only double that found in the Solid Fiberboard boxes. There has also been a much smaller increase in defects since the pallets left Alaska, where there were 71 defects among 59 boxes: merely a 15% and 8% increase respectively.

Figure 88. Pallets laid out for inspection

Figure 89. Other pallets stored at the TISA

Figure 90. Loose cases of MREs stored at the TISA

Figure 91. More loose cases of MREs stored at the TISA

Figure 92. Test Pallets stacked up for storage following completion of inspection

Figure 93. Significantly damaged edge of a pallet.

Figure 94. Large dent on edge of box on pallet

None of the damage to the food packaging components appeared to be caused by the defects in the fiberboard packaging. No damage to the food components were observed in the CF boxes. Previously in Alaska, double the internal damages were found in the CF boxes compared to SF boxes, but this leg of the demonstration shows that this was not a correlative discovery. Nearly all of the CF boxes showed adhesive failure in that the glue was not making a good bond with the box – a new adhesive or adhesive technique needs to be found.

6.8 Waste-to-energy

During feedstock preparation variations on the recipes were incorporated to improve the pellet quality. The decision was made to modify the recipes for the two types of feedstock in order to get viable pellets with the smallest recipe modifications possible. The recipes can be found in Table 58.

Table 58. Recipe for the Waste-to-energy Converter

	12/7/16 Control Recipe (wt%)	**12/8/16 Control Recipe (wt%)**	**Trial Feedstock Recipe #1 (wt%)**	**Trial Feedstock Recipe #2 (wt%)**
Fiberboard	51%	54%	63%	54%
Dog food (Whiskers and Tails Kibbles)	11%	6%	8%	6%
Oil (Vegetable)	1%	1%	1%	1%
Water (tap water, rainwater)	31%	33%	22%	33%
Plastic (polyethylene shelving)	6%	6%	7%	6%
Preparation Notes	Initial pellets made with the Trial #2 recipe did not generate pellets at all. Processed 264 lbs with marginal pellet quality with this high dogfood recipe	Switched back to this recipe but altered the preparation to promote free water exposure to the fiberboard. The result was damp and softened fiberboard that facilitated making higher quality pellets	Processed 180lbs without much pellet consistency. Food mixture was made the night before so there was very little free water to absorb with the cardboard	Addition of more free water seemed to increase moisture take-up in cardboard

A total of 342 lbs of trial feedstock was processed. The pellet runs varied in quality but a typical fines percentage was 9-10%. A total of 315 lbs of pellets were produced and after filtering the fines 309 lbs trial pellets were fed to the reactor.

A total of 429 lbs of control feedstock was processed. The fines percentage using control recipe #1 was 27%, hence the change to control recipe #2. Using control recipe #2, the fines were slightly reduced to 24%. A total of 328 lbs of control feedstock pellets were fed to the reactor. At the end of the control feedstock run, the waste-generated pellets left over from 12/5/16 were added to the reactor to extend the run.

The two types of MRE packaging were compared using data from qualitative and quantitative pellet analysis, solid waste discharge composition analysis, emissions testing and energy production. Syngas samples were taken in triplicate for trash, control and trial fiberboard runs and sent for analysis at Pace Analytical. Unfortunately, the laboratory facility was unable to gather adequate samples from the vials. Energy data taken from the fiberboard study was discussed in this section and does provide some degree of measure of the syngas energy content and quality.

The trial fiberboard was able to produce significantly better pellet uniformity, meaning there was much fewer fines separated from the pellets. Once screen-filtered, the pellets were of similar consistency and had adequate aspect ratio (Figure 96)

Figure 95. Pellets after filtering out the fines, from left to right, made from 12/5/16 trash, Recipe #2 control feedstock, Recipe #2 trial feedstock

The ash was collected from the reactor runs. Each ash sample was analyzed at Pace Analytical Services. A summary of the results can be found in Figure 164 and in Table 59. Several of the analytes were below the practical quantification threshold. Those that were detected at registered levels seemed to be higher in the trial feedstock ash.

Table 59. Ash analysis

Sample Number	Collection Date	Feedstock Type	MethodRef	CasNo	Analyte	Result	PQL	MDL	AnalyticalUnits
N1518-ASH03	12/8/2016	Control FB Feedstock	ASTM D 2974-87	pmoisture	Percent Moisture	9.2	0.1	0.1	%
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7440-38-2	Arsenic	<0.530	0.53	0.47	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7440-39-3	Barium	91.1	2.1	0.089	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7440-43-9	Cadmium	<0.320	0.32	0.032	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7440-47-3	Chromium	3.9	0.53	0.078	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7439-92-1	Lead	<0.530	0.53	0.5	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 7471A	7439-97-6	Mercury	<0.1	0.1	0.0018	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7782-49-2	Selenium	<0.850	0.85	0.48	mg/kg
N1518-ASH03	12/8/2016	Control FB Feedstock	SW-846 6010B	7440-22-4	Silver	<0.640	0.64	0.15	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	ASTM D 2974-87	pmoisture	Percent Moisture	2.7	0.1	0.1	%
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7440-38-2	Arsenic	<0.510	0.51	0.45	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7440-39-3	Barium	216	2.1	0.086	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7440-43-9	Cadmium	8	0.31	0.031	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7440-47-3	Chromium	70.8	0.51	0.075	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7439-92-1	Lead	3.6	0.51	0.49	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 7471A	7439-97-6	Mercury	<0.099	0.099	0.0017	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7782-49-2	Selenium	<0.820	0.82	0.47	mg/kg
N1518-ASH04	12/7/2016	Trial FB Feedstock	SW-846 6010B	7440-22-4	Silver	<0.620	0.62	0.15	mg/kg

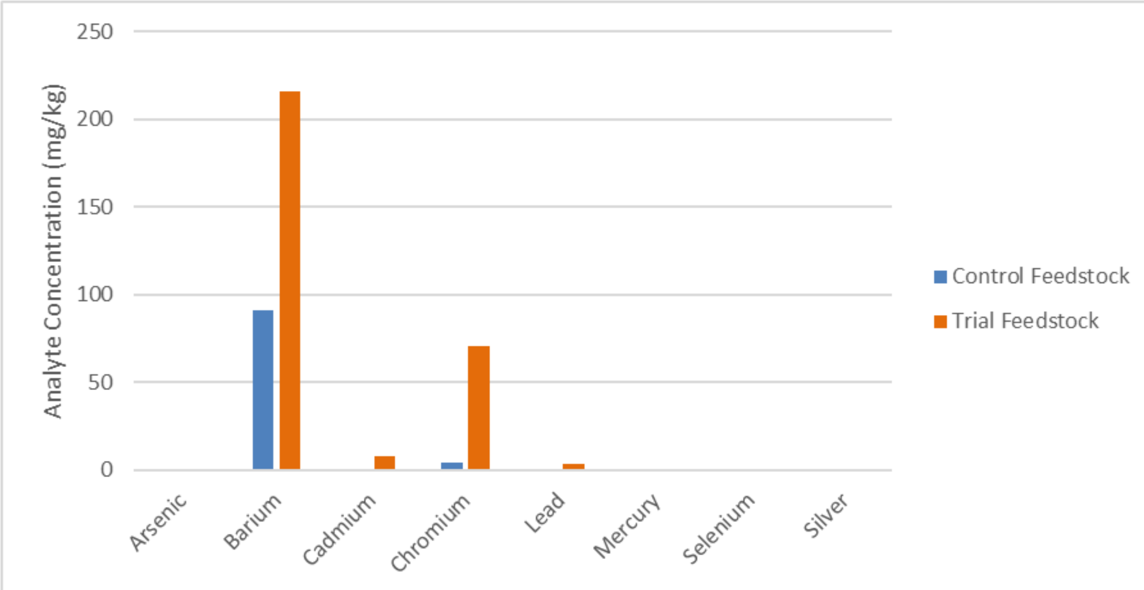


Figure 96. Ash Analysis for control and trial feedstock

A Testo 335 emissions tester was used to perform onsite sampling of the genset exhaust. The results are shown in Table 14. It was determined that the new fiberboard has no impact on the emissions profile of the diesel genset tasked with converting producer gas into electricity.

Table 60. Emissions test results for two trial runs (Emission data was not corrected for oxygen in exhaust stream)

Analyte	Trial Fiberboard Operations (g/BHP-hr)	Control Fiberboard Operations (g/BHP-hr)
CO	34.34	28.22
NO_x	2.76	2.80

Figure 97 shows the generator performance profile for the Trial feedstock operations on 12/7/2016. The pellets were fed to the reactor at 11:24 am and the emissions testing was conducted at 12:23 pm. The unstable nature of this run can be seen from the rapid rise and fall of the power generator output. With increased stability, better performance was achieved.

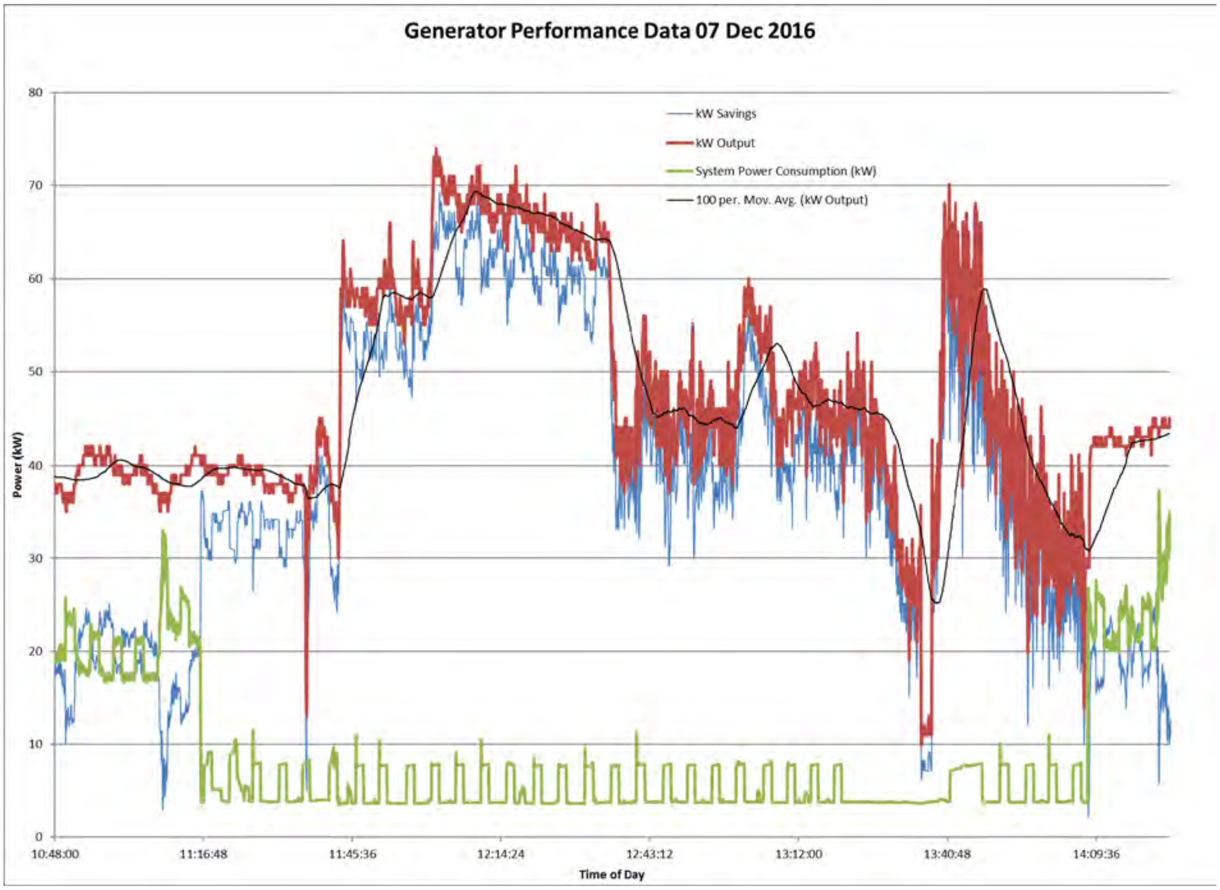


Figure 97. Generator performance data for the trial feedstock on 12/7/2016

Figure 98: Generator performance data for the control feedstock on 12/8/2016 shows the generator performance profile for the Control feedstock operations on 12/8/2016. The pellets were fed to the reactor at 12:04 pm and the emissions testing was conducted at 14:23 pm. This run was much more stable, sustaining around 75 kW output for over 90 minutes.

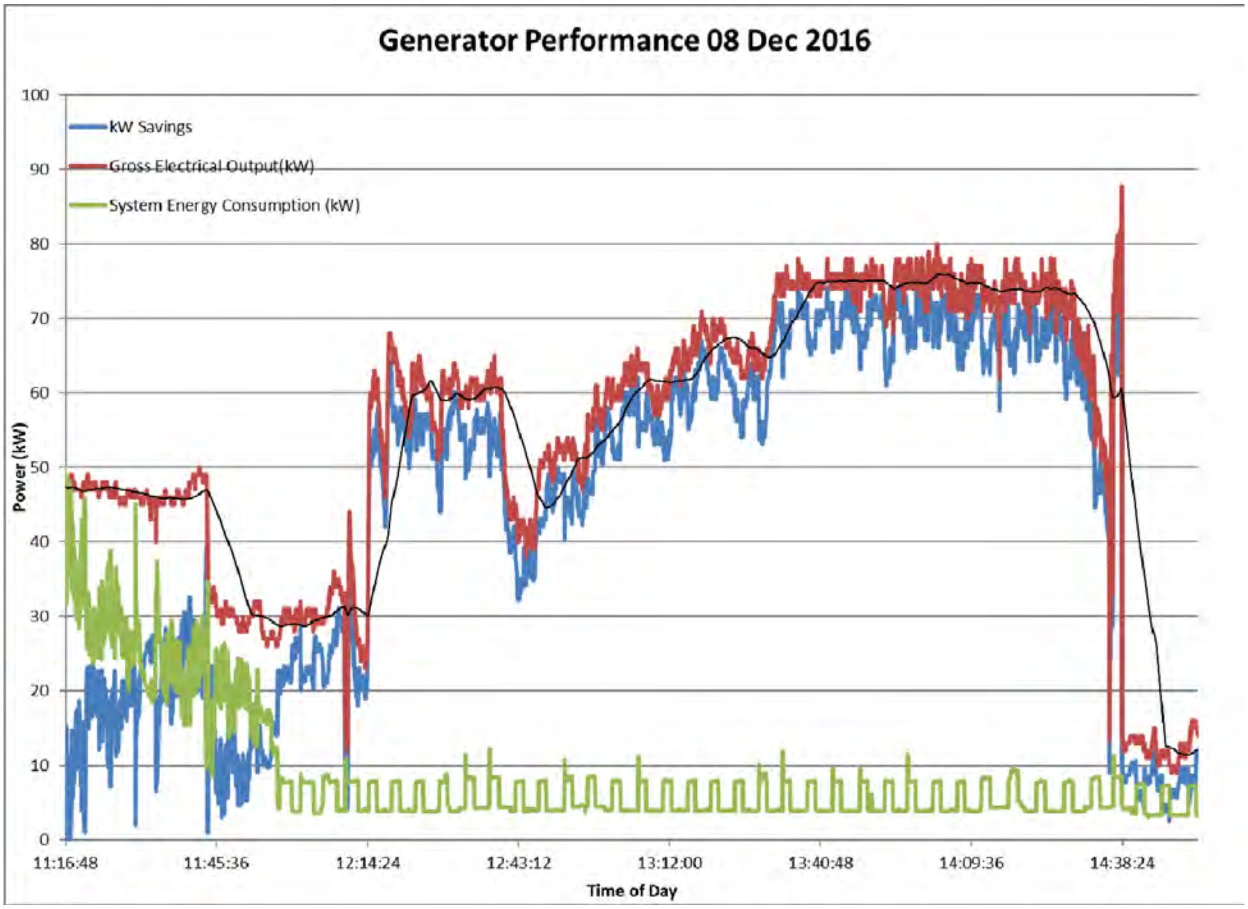


Figure 98: Generator performance data for the control feedstock on 12/8/2016

A summary of the BWEC system performance test results for the two MRE packaging material can be found in Table 61: Performance test results for two trial runs). As discussed above, the second operational day was run under a stabilized condition set. These stable conditions may have factored in the improved performance of the system. The primary outcome from the performance test data was that the BWEC system was able to process both the control and trial packaging materials and provide adequate power generation.

Table 61: Performance test results for two trial runs

Performance Metric	Trial Fiberboard Operations (12/7/16)	Control Fiberboard Operations (12/8/16)
Gasifier Pellet Flowrate (lbs/hr)	133.29	203.92
Max sustained kW output	73	79
Average kW Output	49.84	63.69
Calculated BTU/SCFM	136.3*	204.5*
BTU/hr : Pellet flowrate (lbs/hr)	1.0	1.0
Ash Output (lbs/hr)	14.23**	19.4
Ash % (gasifier in/out)	10.7	9.7

*Assumes engine efficiency which was the same in both calculations

** This number was derived from total ash over time of processing while 12/8 data point was based upon several time and weight data points.

6.9 Fiberboard Packaging Emissions

Typical traces of PM, CO, and CO_2 throughout each of the fiberboard burns are shown in below. In general, concentrations of CO and CO_2 mimic the increase in particle concentration. Peak particle concentrations range from 10-20 mg/m^3, although one packaging type, NWS, exceeded 50 mg/m^3. The similarity of the PM_1 to Total PM traces indicates that the majority of the particles are small, < 1 µm, and therefore respirable. This examines PM emission factors with time over the replicates and also plots MCE to see if there was any relationship between PM emissions and combustion quality. While most of the runs have consistent, packaging-specific emission factors, the variance in a few runs illustrates the effect of random waste orientation on emissions. Also, while there are suggestions from limited tests that poor combustion quality (low MCE) increases PM emissions (NSB/NSL R2 of 0.81 and SB/SL R^2 of 0.55, figure not shown), the correlations seem inconsistent (CB/CL R^2 of 0.056 and NWS R^2 of 0.056, figure not shown). Single factor ANOVA showed no statistical difference between the PM emission factors for the different fiberboard types ($F = 0.24$, $p = 0.56$).

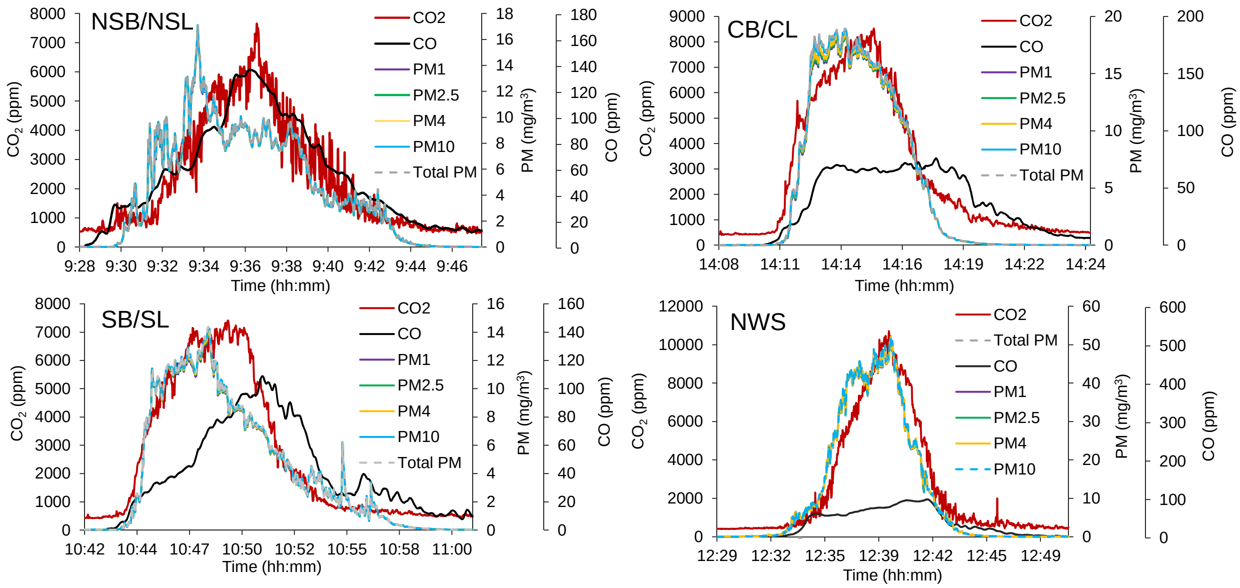


Figure 99. Typical traces of PM, CO, and CO_2 throughout each of the fiberboard type burns.

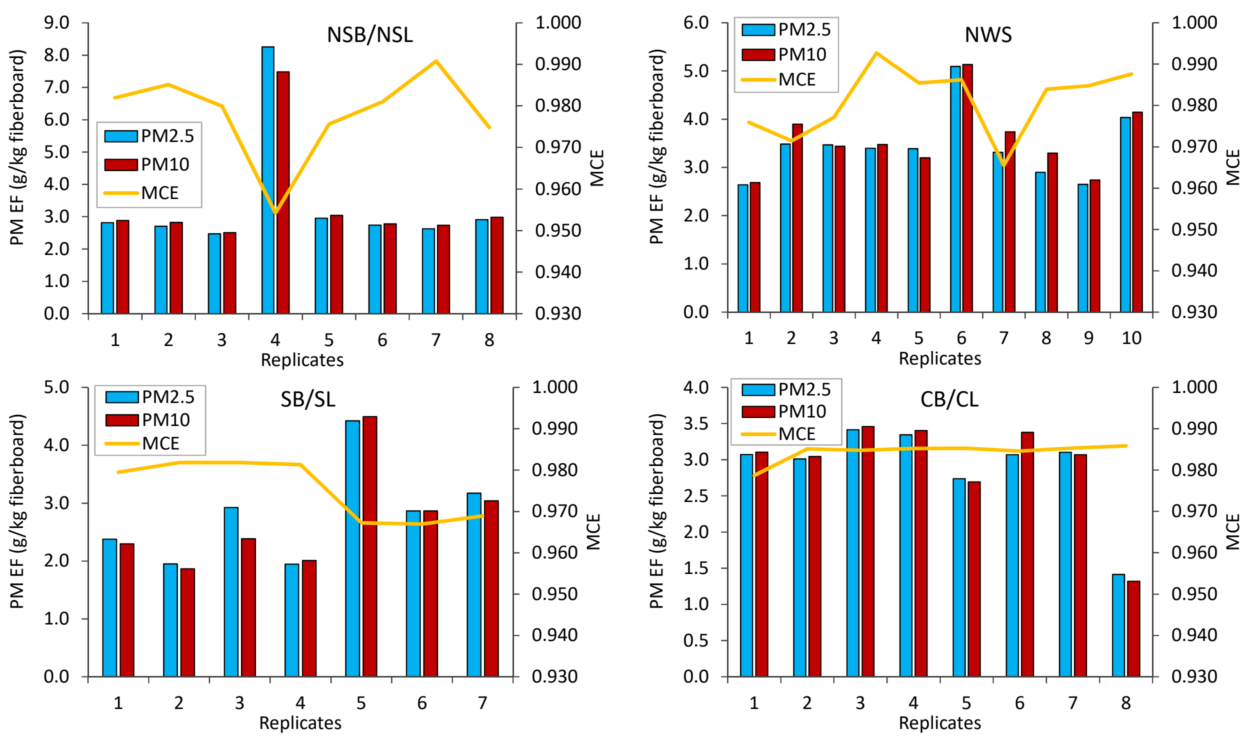


Figure 100. $PM_{2.5}$ and PM_{10} emission factors and modified combustion efficiency (MCE) for each replicate.

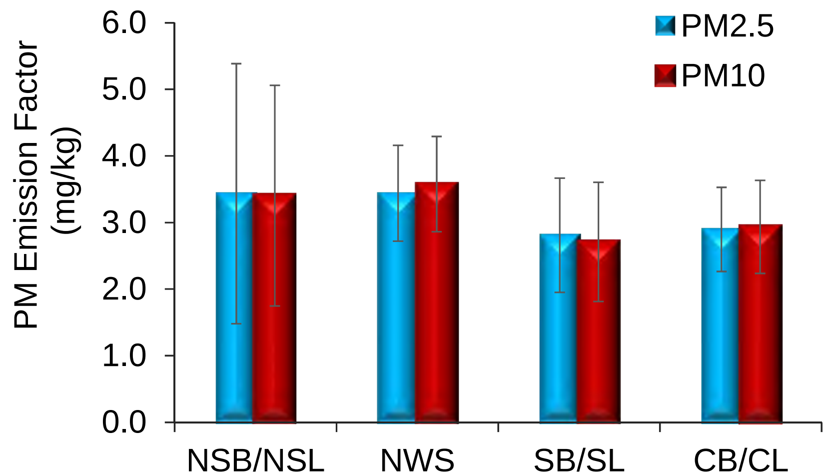


Figure 101. $PM_{2.5}$ and PM_{10} emission factors from open burning of fiberboard. Error bars represent 1 STDV.

Table 62. PM emission factors.

Paperboard	$PM_{2.5}$ mg/kg Paperboard Average	$PM_{2.5}$ mg/kg Paperboard STDV	PM_{10} mg/kg Paperboard Average	PM_{10} mg/kg Paperboard STDV
NSB/NSL	3.4	1.95	3.4	1.66
NWS	3.4	0.72	3.6	0.72
SB/SL	2.8	0.86	2.7	0.89
CB/CL	2.9	0.63	2.9	0.70

6.9.1 Metals and Other Trace Elements

Emission factors for metals and other trace elements are shown in Table 62. PM emission factors. No effect on the emission factors was found for the different MRE waste compositions. Chlorine (Cl), Sulfur (S), Potassium (K) were the most abundant elements observed. The Al emission factors were very similar for the four MRE waste compositions, 2.3-2.8 mg/kg MRE.

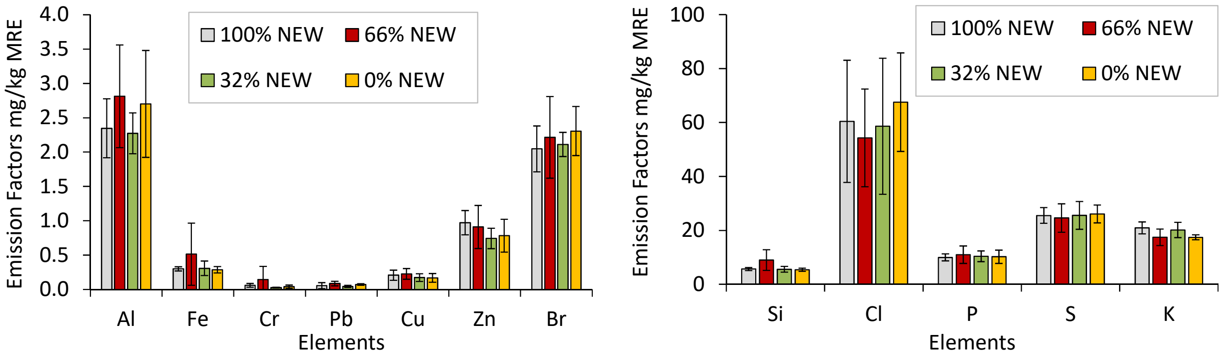


Figure 102. Major metal and trace /element emission factors from open burning of MRE's.

Figure 103. Major metal and trace /element emissions from open burning of MRE pouches.[a]

	NEW							
	100 %		66 %		32 %		0 %	
Element	**mg/kg**	**STDV**	**mg/kg**	**STDV**	**mg/kg**	**STDV**	**mg/kg**	**STDV**
Al	2.3	0.43	2.8	0.75	2.3	0.30	2.7	0.78
Fe	0.30	0.030	0.51	0.45	0.31	0.11	0.29	0.046
Cr	0.059	0.027	0.15	0.19	0.027	0.0058[b]	0.040	0.025
Pb	0.056	0.044	0.086	0.033	0.045	0.016	0.071	0.012
Cu	0.21	0.075	0.23	0.079	0.17	0.057	0.17	0.062
Zn	0.97	0.18	0.91	0.31	0.74	0.15	0.78	0.24
Br	2.0	0.33	2.2	0.59	2.1	0.18	2.3	0.36
Si	5.7	0.56	9.0	3.8	5.6	1.1	5.4	0.6
Cl	60	23	54	18	59	25	68	18
P	10	1.3	11	3.2	10	2.0	10	2.5
S	26	2.9	25	5.3	26	5.2	26	3.3
K	21	2.2	17	3.1	20	2.8	17	0.91

[a] The metals and trace elements here were selected based on the number of samples where the material was detected more than three times the uncertainty level of the analysis.. [b] Relative difference.

6.9.2 Fiberboard packaging

Results for select VOC emission factors for the MRE fiberboard packaging burns are shown in the Figures below. For the four packaging types, benzene was the most prevalent VOC at approximately 80 to 150 mg/kg of fiberboard material. For three of the four materials, acrolein was the next most prevalent. Typical combustion-related aromatic pollutants (benzene, toluene, acrolein, and xylenes) are linearly related to the MCE value

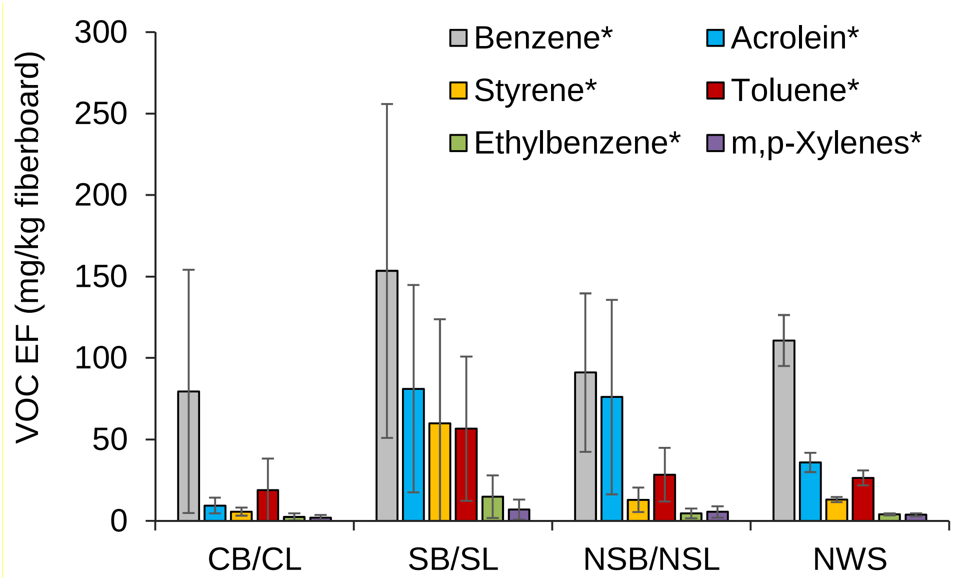


Figure 104. Select VOCs and their emission factors for the different fiberboard types. * = on EPA's list of hazardous air pollutants.

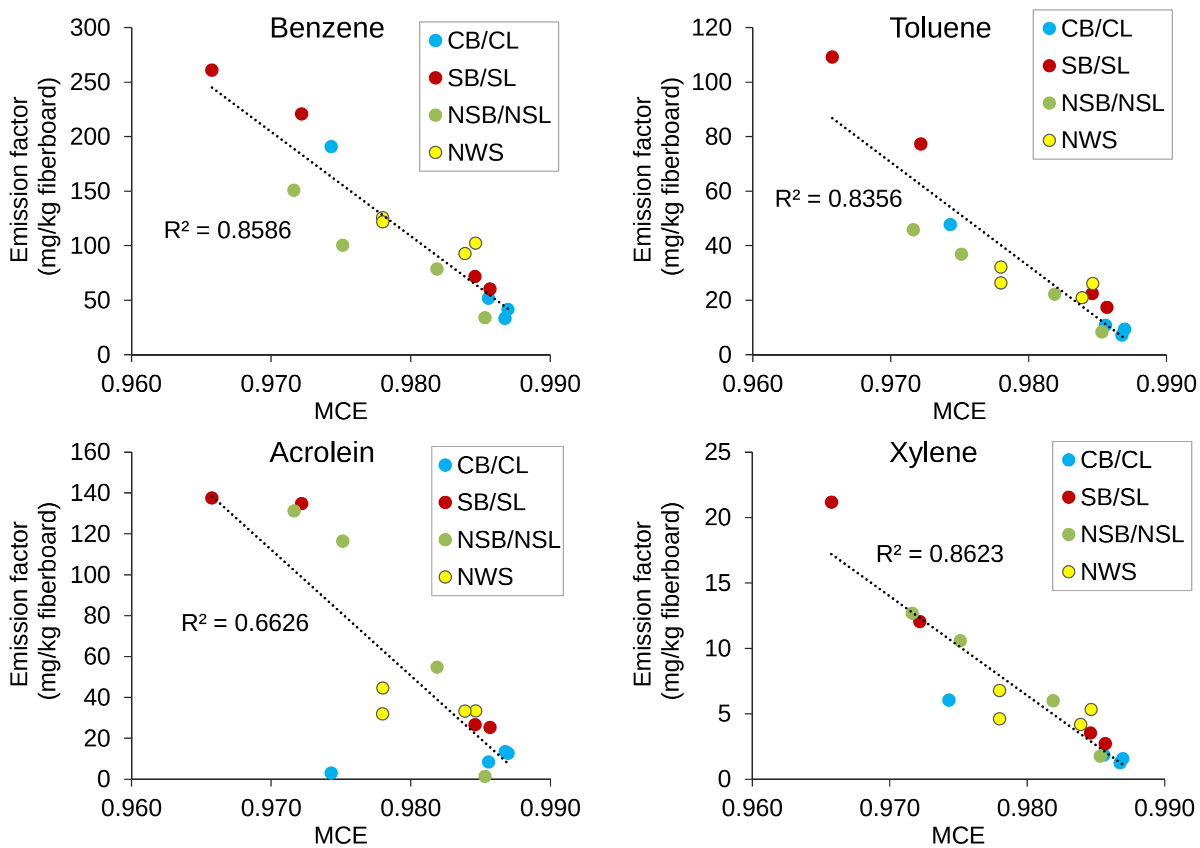


Figure 105. Select VOCs versus modified combustion efficiency (MCE).

Table 63. VOC emission factors.

Compound	CB/CL Average mg/kg	CB/CL STDV mg/kg	SB/SL Average mg/kg	SB/SL STDV mg/kg	NSB/NSL Average mg/kg	NSB/NSL STDV mg/kg	NWS Average mg/kg	NWS STDV mg/kg
Benzene[a]	79	75	153	102	91	49	111	16
Propene	38	42	118	94	84	57	51	9.4
Vinyl Acetate[a]	33	13	98	70	50	NA	48	9.7[b]
Acrolein[a]	9.4	4.8	81	64	76	60	36	5.9
Toluene[a]	19	19	57	44	28	16	26	4.6
1,3-Butadiene[a]	19	22	44	43	34	23	24	5.3
Styrene[a]	5.6	2.5	60	64	13	7.5	13	1.6
2-Butanone (MEK)	9.3	11	23	19	24	16	10	3.0
Ethylbenzene[a]	2.4	2.2	15	13	4.6	2.9	4.1	0.60
Methylene Chloride	5.5	5.3	2.2	2.1[b]	3.1	3.4	6.7	5.3
m-,*p*-Xylenes[a]	1.9	1.7	6.9	6.1	5.5	3.5	3.7	0.82
o-Xylene[a]	0.74	0.58	2.9	2.6	2.2	1.4	1.5	0.32
Acetonitrile	1.2	1.1	3.0	2.0	1.6	0.84	0.62	0.10
Cumene[a]	0.33	NA	1.5	1.4	0.29	0.12	0.20	0.027

[a] Included in the EPA list of hazardous air pollutants. [b] Relative difference. NA = not applicable. The VOCs shown here were selected based on the number of samples where the compound was detectable above three times the detection limit with relevance to the EPA's list of hazardous air pollutants.

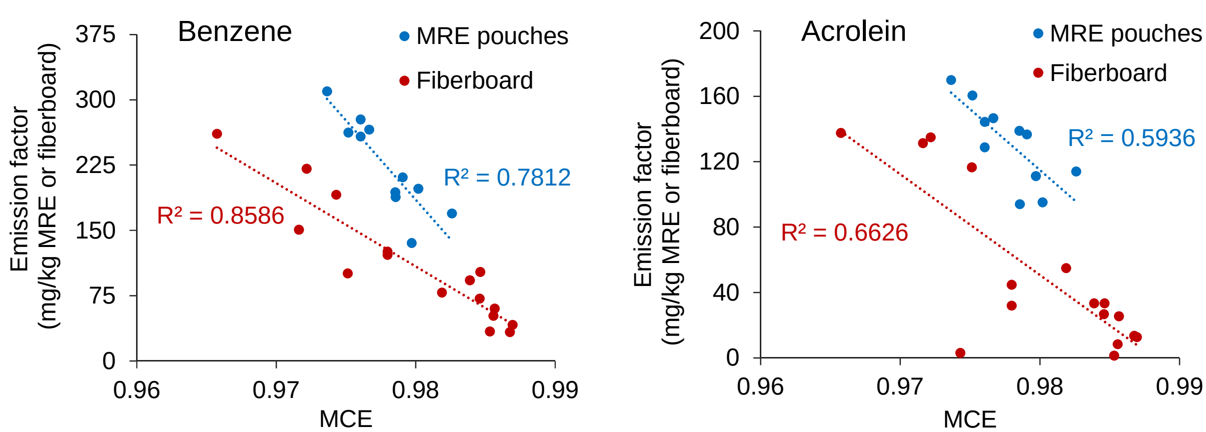


Figure 106. Benzene and acrolein vs. MCE for all MRE waste compositions and fiberboard types burns.

6.9.3 PAHs Fiberboard packaging

Fiberboard burns resulted in PAH emission factors as shown as individual PAHs and TEF-weighted PAHs.
No difference was seen between the fiberboard types (single factor ANOVA, $F = 0.51$, $p = 0.20$); PAH emissions are the same no matter what fiberboard type.

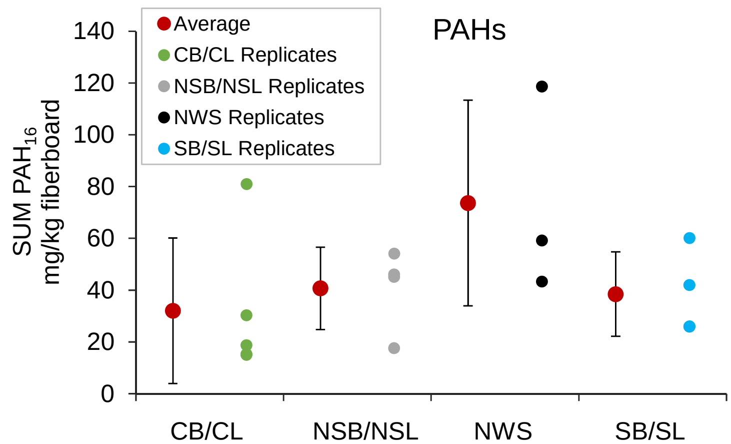


Figure 107. PAH emission factors from open burning of fiberboard packaging. Error bars represent 1 standard deviation.

Table 64. PAH emission factors from open burning of fiberboard in mg/kg fiberboard.

Compound	NWS Average mg/kg Fiberboard	NWS STDV mg/kg Fiberboard	CB/CL Average mg/kg Fiberboard	CB/CL STDV mg/kg Fiberboard	NSB/NSL Average mg/kg Fiberboard	NSB/NSL STDV mg/kg Fiberboard	SB/SL Average mg/kg Fiberboard	SB/SL STDV mg/kg Fiberboard
Naphthalene	28	21	14	15	21	9.9	15	6.7
Acenaphthylene	13	9.3	5.5	5.2	6.9	2.7	4.8	2.2
Acenaphthene	0.68	0.45	0.24	0.18	0.43	0.19	0.35	0.20
Fluorene	3.0	1.6	1.1	0.86	1.4	0.56	1.8	0.79
Phenanthrene	10	4.7	4.3	3.0	4.4	1.3	6.8	3.0
Anthracene	2.4	1.3	0.89	0.64	0.99	0.33	1.7	0.87
Fluoranthene	4.9	2.7	2.0	0.93	1.8	0.29	2.7	1.2
Pyrene	4.5	2.5	1.8	0.80	1.7	0.24	2.4	1.1
Benzo(a)anthracene	1.2	0.65	0.44	0.27	0.44	0.13	0.75	0.35
Chrysene	1.1	0.57	0.43	0.28	0.41	0.11	0.72	0.34
Benzo(b)fluoranthene	0.62	0.32	0.24	0.14	0.23	0.068	0.33	0.16
Benzo(k)fluoranthene	0.91	0.45	0.31	0.18	0.27	0.055	0.40	0.17
Benzo(a)pyrene	1.0	0.55	0.34	0.22	0.31	0.067	0.46	0.22
Indeno(1,2,3-cd)pyrene	0.66	0.33	0.22	0.13	0.20	0.035	0.28	0.13
Dibenz(a,h)anthracene	0.11	0.067	0.041	0.030	0.037	0.011	0.067	0.038
Benzo(ghi)perylene	0.73	0.37	0.26	0.18	0.21	0.035	0.27	0.11
SUM 16-EPA PAH	**74**	**40**	**32**	**28**	**41**	**16**	**38**	**16**

Table 65. PAH TEQ emission factors from open burning of fiberboard in mg B[a]P TEQ/kg fiberboard.[a]

	NWS		CB/CL		NSB/NSL		SB/SL	
	Average	STDV	Average	STDV	Average	STDV	Average	STDV
Compound	**mg B[a]P TEQ/kg Fiberboard**							
Naphthalene	NA	NA	NA	NA	NA	NA	NA	NA
Acenaphthylene	NA	NA	NA	NA	NA	NA	NA	NA
Acenaphthene	NA	NA	NA	NA	NA	NA	NA	NA
Fluorene	NA	NA	NA	NA	NA	NA	NA	NA
Phenanthrene	5.1E-03	2.4E-03	2.1E-03	1.5E-03	2.2E-03	6.4E-04	3.4E-03	1.5E-03
Anthracene	1.2E-03	6.3E-04	4.4E-04	3.2E-04	5.0E-04	1.6E-04	8.4E-04	4.3E-04
Fluoranthene	2.5E-01	1.3E-01	9.8E-02	4.6E-02	8.8E-02	1.4E-02	1.3E-01	5.9E-02
Pyrene	4.5E-03	2.5E-03	1.8E-03	8.0E-04	1.7E-03	2.4E-04	2.4E-03	1.1E-03
Benzo(a)anthracene	5.9E-03	3.3E-03	2.2E-03	1.4E-03	2.2E-03	6.3E-04	3.7E-03	1.7E-03
Chrysene	3.2E-02	1.7E-02	1.3E-02	8.4E-03	1.2E-02	3.3E-03	2.2E-02	1.0E-02
Benzo(b)fluoranthene	6.2E-02	3.2E-02	2.4E-02	1.4E-02	2.3E-02	6.8E-03	3.3E-02	1.6E-02
Benzo(k)fluoranthene	4.5E-02	2.3E-02	1.5E-02	9.2E-03	1.3E-02	2.7E-03	2.0E-02	8.3E-03
Benzo(a)pyrene	1.0E+00	5.5E-01	3.4E-01	2.2E-01	3.1E-01	6.7E-02	4.6E-01	2.2E-01
Indeno(1,2,3-cd)pyrene	6.6E-02	3.3E-02	2.2E-02	1.3E-02	2.0E-02	3.5E-03	2.8E-02	1.3E-02
Dibenz(a,h)anthracene	6.2E-02	7.3E-02	2.5E-02	1.8E-02	3.4E-02	2.4E-02	6.4E-02	5.5E-02
Benzo(ghi)perylene	1.5E-02	7.3E-03	5.3E-03	3.5E-03	4.2E-03	7.0E-04	5.4E-03	2.3E-03
SUM 16-EPA PAH	**1.6E+00**	**8.2E-01**	**5.4E-01**	**3.1E-01**	**5.1E-01**	**1.2E-01**	**7.7E-01**	**3.8E-01**

[a] NA – not applicable (no TEF value).

6.9.4 MRE pouches

MRE burns resulted in PAH emission factors as shown for sums individual PAHs, and TEF-weighted PAHs. Single factor ANOVA ($F = 0.24$, $p = 0.44$) showed no difference in PAH emissions among the different MRE waste categories. However, a weak difference was seen between the different MRE waste categories and CB/CL fiberboard type ($F = 1.04$, $p = 0.045$). Higher PAH emissions resulted from burning MREs and CB/CL together. No difference was seen between the MRE types. PAH emissions are the same no matter what MRE waste category

6.9.5 PCDD/PCDF Fiberboard Packaging

Emission values for the MRE shipping containers show PCDD/PCDF emission factors that are low compared to the cellulosic biomass [18]. One emission factor value, however, that of SB/SL, stands out from the other fiberboard types as being distinctively high. Paired single factor ANOVA analyses showed a significant difference between SB/SL and the other fiberboard types ($F = 1.43, 1.02, 2.61$ and $p = 0.026, 0.048, 0.0065$). The same high value for SB/SL results when examining the PCDD/PCDF total value consisting of the sum of all of the homolog concentrations. The results are internally consistent in that the 1,2,3,7,8 – PeCDD congener and the 2,3,4,7,8 – PeCDF congener consistently contribute the most to their respective TEQ values. A number of compositional factors may have resulted in this comparatively higher PCDD/PCDF value, including lower calorific value, higher loss on drying, higher chloride, and lower sulfur. In general, better combustion (processes with higher fuel calorific value and lower moisture content) results in lower PCDD/PCDF formation due to the diminished availability of organic precursors. Higher chloride values and lower sulfur values have generally been associated with increased formation of PCDD/PCDF, the former acting as a chlorination promotor, and the latter acting to suppress PCDD/PCDF formation.

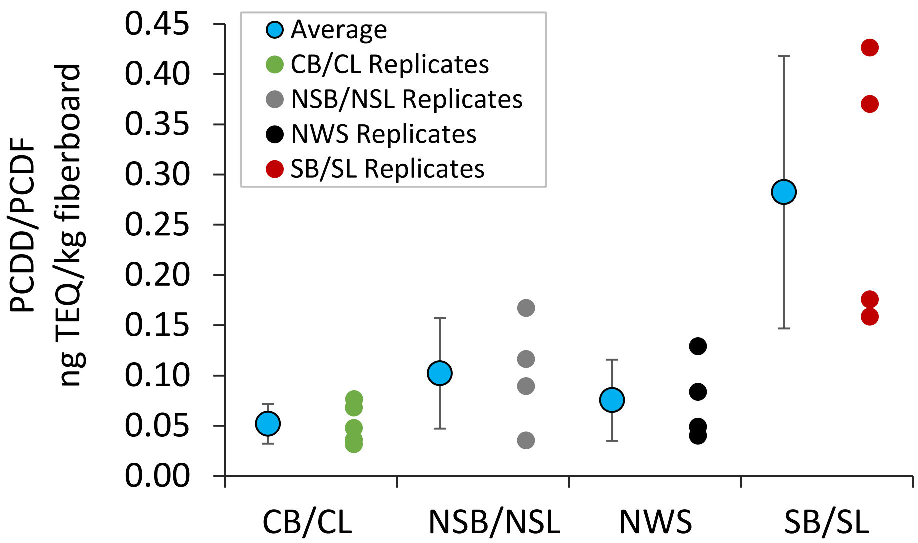


Figure 108. PCDD/PCDF emission factors from open burning of fiberboard packaging. Error bars represent 1 standard deviation.

Table 66. PCDD/PCDF TEQ emission factors.

isomer.	CB/CL Average	CB/CL STDV	NSB/NSL Average	NSB/NSL STDV	NWS Average	NWS STDV	SB/SL Average	SB/SL STDV
	ng TEQ/kg fiberboard							
2,3,7,8 - TCDD	3.20E-03	1.51E-03	1.25E-02	2.17E-03	6.05E-03	2.11E-03	2.76E-02	1.78E-02
1,2,3,7,8 - PeCDD	1.26E-02	3.95E-03	5.17E-02	2.36E-02	1.63E-02	7.55E-03	1.18E-01	8.06E-02
1,2,3,4,7,8 - HxCDD	8.22E-04	3.42E-04	2.78E-03	9.28E-04	1.06E-03	4.28E-04	6.70E-03	4.21E-03
1,2,3,6,7,8 - HxCDD	1.68E-03	4.09E-04	9.23E-03	3.54E-03	1.72E-03	7.64E-04	2.07E-02	1.25E-02
1,2,3,7,8,9 - HxCDD	1.40E-03	4.57E-04	6.74E-03	2.60E-03	1.52E-03	4.28E-04	1.54E-02	9.77E-03
1,2,3,4,6,7,8 - HpCDD	1.75E-03	4.93E-04	1.20E-02	3.91E-03	1.65E-03	4.17E-04	2.52E-02	1.19E-02
1,2,3,4,6,7,8,9 - OCDD	1.44E-04	3.82E-05	1.01E-03	2.52E-04	1.26E-04	4.01E-05	2.05E-03	7.88E-04
2,3,7,8 - TCDF	9.26E-03	6.22E-03	7.09E-03	1.13E-03	8.71E-03	4.93E-03	2.38E-02	4.96E-03
1,2,3,7,8 - PeCDF	9.13E-04	3.74E-04	5.70E-04	3.88E-04	1.38E-03	1.16E-03	2.03E-03	2.47E-04
2,3,4,7,8 - PeCDF	9.76E-03	3.25E-03	7.40E-03	5.07E-03	1.97E-02	1.30E-02	2.56E-02	2.47E-03
1,2,3,4,7,8 - HxCDF	2.72E-03	1.30E-03	2.63E-03	5.45E-04	5.66E-03	3.38E-03	4.52E-03	8.73E-04
1,2,3,6,7,8 - HxCDF	2.42E-03	1.26E-03	2.05E-03	6.52E-04	5.02E-03	3.58E-03	3.51E-03	2.94E-04
1,2,3,7,8,9 - HxCDF	1.30E-03	8.81E-04	7.22E-04	7.79E-05	2.26E-03	1.21E-03	1.39E-03	1.68E-04
2,3,4,6,7,8 - HxCDF	3.52E-03	2.73E-03	2.18E-03	4.74E-04	5.79E-03	2.59E-03	4.58E-03	6.47E-04
1,2,3,4,6,7,8 - HpCDF	8.86E-04	8.01E-04	6.68E-04	1.17E-04	1.23E-03	5.72E-04	1.23E-03	2.30E-04
1,2,3,4,7,8,9 - HpCDF	1.60E-04	1.43E-04	1.31E-04	3.58E-05	2.33E-04	1.66E-04	2.23E-04	7.03E-05
1,2,3,4,6,7,8,9 - OCDF	1.67E-05	1.46E-05	2.48E-05	5.44E-06	2.27E-05	1.23E-05	4.86E-05	9.76E-06
PCDD TEQ Total	**2.09E-02**	**6.50E-03**	**7.92E-02**	**4.94E-02**	**2.54E-02**	**1.11E-02**	**2.16E-01**	**1.37E-01**
PCDF TEQ Total	**3.09E-02**	**1.36E-02**	**2.27E-02**	**5.70E-03**	**5.00E-02**	**2.95E-02**	**6.70E-02**	**6.04E-03**
PCDD/PCDF TEQ Total	**5.19E-02**	**1.97E-02**	**1.02E-01**	**5.50E-02**	**7.54E-02**	**4.05E-02**	**2.83E-01**	**1.36E-01**

Table 67. PCDD/PCDF Total emission factors.

Homologue	CB/CL Average	CB/CL STDV	NSB/NSL Average	NSB/NSL STDV	NWS Average	NWS STDV	SB/SL Average	SB/SL STDV
TeCDD	0.35	0.089	0.39	0.13	0.39	0.12	0.84	0.40
PeCDD	0.18	0.040	0.31	0.17	0.20	0.033	0.80	0.47
HxCDD	0.19	0.060	0.67	0.30	0.19	0.016	1.7	1.0
HpCDD	0.31	0.10	1.9	0.65	0.29	0.071	4.0	1.9
OCDD	0.48	0.13	3.4	0.84	0.42	0.13	6.8	2.6
TeCDF	1.29	0.73	0.93	0.15	1.55	1.09	2.6	0.36
PeCDF	0.37	0.083	0.30	0.14	0.67	0.52	0.84	0.11
HxCDF	0.24	0.14	0.19	0.05	0.47	0.28	0.36	0.024
HpCDF	0.17	0.15	0.17	0.03	0.24	0.12	0.34	0.074
OCDF	0.069	0.043	0.086	0.023	0.076	0.041	0.16	0.033
PCDD Total	1.5	0.37	**6.7**	**2.0**	**1.5**	**0.34**	**14**	**6.3**
PCDF Total	2.1	0.84	**1.7**	**0.30**	**3.0**	**2.0**	**4.3**	**0.48**
PCDD/PCDF Total	3.6	1.2	**8.3**	**2.2**	**4.5**	**2.2**	**19**	**6.6**

Figure 109. Fiberboard PCDD/PCDF emission factors versus modified combustion efficiency (MCE).compared to the PCDD/PCDF TEQ values versus MCE, indicating a moderate, negatively correlating relationship. Formation of PCDD/PCDF has historically been tied to marginal combustion, likely due to the presence of surviving organic structures providing the template for chlorination and ring formation.

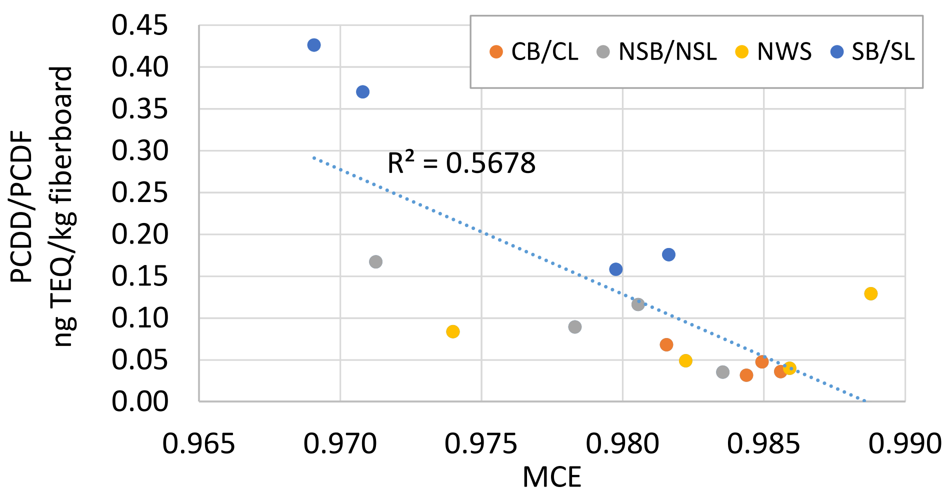


Figure 109. Fiberboard PCDD/PCDF emission factors versus modified combustion efficiency (MCE).

Figure 110. PCDD/PCDF TEQ emission factors.

Isomer.	0% New Average	0% New STDV	32% New Average	32% New STDV	66% New Average	66% New STDV	100% New Average	100% New STDV
	ng TEQ/kg MRE							
2,3,7,8 - TCDD	2.9E-01	2.4E-01	6.4E-02	3.5E-02	3.3E-02	2.1E-02	6.5E-02	4.2E-02
1,2,3,7,8 - PeCDD	1.3E-01	2.2E-02	8.8E-02	2.3E-02	3.6E-02	1.6E-02	8.6E-02	3.4E-02
1,2,3,4,7,8 - HxCDD	5.4E-03	2.1E-03	3.3E-03	1.1E-03	2.2E-03	4.1E-04	3.3E-03	1.3E-03
1,2,3,6,7,8 - HxCDD	7.2E-03	6.3E-03	7.8E-03	1.2E-03	6.4E-03	1.1E-03	8.0E-03	1.2E-03
1,2,3,7,8,9 - HxCDD	6.0E-03	5.3E-03	7.2E-03	2.0E-03	5.9E-03	8.6E-04	6.3E-03	5.4E-04
1,2,3,4,6,7,8 - HpCDD	1.2E-02	5.1E-04	8.8E-03	4.8E-04	9.0E-03	4.3E-04	9.8E-03	7.2E-04
1,2,3,4,6,7,8,9 - OCDD	9.9E-04	9.1E-05	7.5E-04	3.6E-05	8.1E-04	3.0E-05	8.7E-04	1.0E-04
2,3,7,8 - TCDF	7.1E-01	4.3E-01	3.4E-01	1.4E-01	9.7E-02	5.8E-02	3.3E-01	2.4E-01
1,2,3,7,8 - PeCDF	4.5E-02	2.4E-02	2.6E-02	7.8E-03	7.4E-03	4.7E-03	2.6E-02	1.7E-02
2,3,4,7,8 - PeCDF	4.8E-01	2.9E-01	2.6E-01	7.4E-02	7.5E-02	4.7E-02	2.5E-01	1.7E-01
1,2,3,4,7,8 - HxCDF	3.6E-02	9.2E-03	2.7E-02	8.4E-03	9.1E-03	3.0E-03	2.8E-02	1.2E-02
1,2,3,6,7,8 - HxCDF	3.2E-02	1.1E-02	2.7E-02	5.4E-03	8.6E-03	3.0E-03	2.4E-02	1.0E-02
1,2,3,7,8,9 - HxCDF	1.1E-02	1.0E-02	1.3E-02	5.5E-03	4.2E-03	1.9E-03	1.1E-02	4.2E-03
2,3,4,6,7,8 - HxCDF	2.7E-02	8.9E-03	2.4E-02	6.3E-03	8.6E-03	3.8E-03	2.1E-02	8.8E-03
1,2,3,4,6,7,8 - HpCDF	3.2E-03	1.3E-04	2.6E-03	6.2E-04	1.5E-03	2.5E-04	2.8E-03	8.6E-04
1,2,3,4,7,8,9 - HpCDF	3.9E-04	3.8E-04	7.4E-04	2.7E-04	2.5E-04	7.3E-05	6.4E-04	2.2E-04
1,2,3,4,6,7,8,9 - OCDF	7.1E-05	7.2E-06	6.3E-05	1.4E-05	4.8E-05	9.1E-06	6.0E-05	2.3E-05
PCDD TEQ Total	4.6E-01	2.6E-01	1.8E-01	5.0E-02	9.1E-02	2.9E-02	1.8E-01	7.5E-02
PCDF TEQ Total	1.3E+00	7.9E-01	7.2E-01	2.4E-01	2.1E-01	1.2E-01	7.0E-01	4.6E-01
PCDD/PCDF TEQ Total	1.8E+00	1.0E+00	9.0E-01	2.9E-01	3.0E-01	1.4E-01	8.8E-01	5.3E-01

Table 68. PCDD/PCDF Total emission factors.

Homologue	0 % New Average	0 % New STDV	32 % New Average	32 % New STDV	66 % New Average	66 % New STDV	100 % New Average	100 % New STDV
	ng/kg MRE							
TeCDD	2.1	0.75	0.95	0.30	0.70	0.14	1.8	0.78
PeCDD	0.96	0.13	0.64	0.18	0.37	0.12	0.92	0.48
HxCDD	1.1	0.16	0.83	0.11	0.64	0.10	0.95	0.23
HpCDD	2.1	0.095	1.5	0.080	1.5	0.095	1.7	0.12
OCDD	3.31	0.30	2.48	0.12	2.71	0.10	2.90	0.34
TeCDF	92	48	57	15	26	8.0	59	25
PeCDF	14	6.5	9.0	2.2	2.4	1.2	8.6	5.3
HxCDF	2.4	0.85	2.0	0.43	0.66	0.25	1.9	0.75
HpCDF	0.49	0.16	0.50	0.14	0.25	0.017	0.44	0.069
OCDF	0.25	0.042	0.22	0.032	0.16	0.030	0.22	0.083
PCDD Total	9.6	0.96	6.4	0.51	5.9	0.52	8.2	1.6
PCDF Total	109	56	69	17	29	9.3	70	31
PCDD/PCDF Total	118	56	75	18	35	9.3	78	32

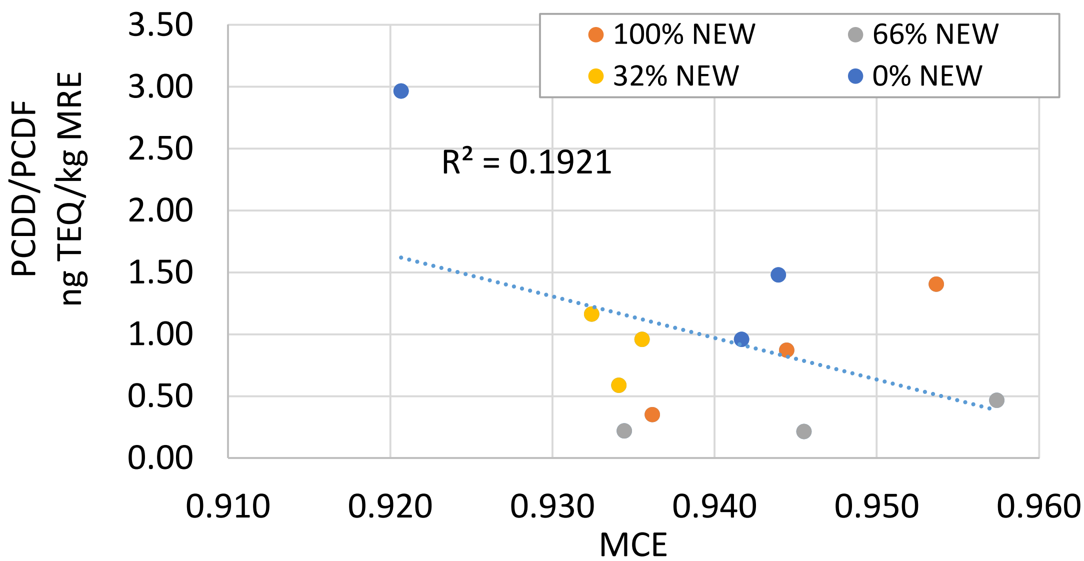


Figure 111. MRE PCDD/PCDF emission factors versus modified combustion efficiency (MCE).

6.9.6 Quality of Data and Data Limitations

For PCDD/PCDF analyses all surrogate standard recoveries were between 63% and 110% for the fiberboard burn samples, which was within the standard method criteria (25-130%). Some of the surrogate standard recoveries were outside the standard method criteria (25-130%) for the MRE burn samples due to interference from significant amounts of other compounds in the ^{13}C channels causing a low response for the compound pre-analysis. For the PAHs all surrogate standard recoveries for method blanks and samples were between 48 and 110 percent, which was within the standard method criteria (25% and 130%). Two method blanks for the VOCs returned all non-detects. All surrogate standard recoveries for method blanks and samples were between 95% and 107%, within the acceptance limits of the method (70-130%). Precision data on the XRF analyses for six elements had less than 3.5% error. The accuracy data on nine standard reference materials ranged from 90.7% to 106.8%. The precision for the gravimetric data was ± 10 µg. The CO_2 calibration error for all test days was between 0.001% and 0.559%, and the system drift was between 0.015% and 0.319%, below the error and drift acceptance criteria of 5% and 3%, respectively, in U.S. EPA Method 3A [14]. CO calibration and post drift tests were performed each test day. The calibration error for all test days was between 0.01% and 1.10%, and the system drift was between 0.66% and 1.57%, below the error and drift acceptance criteria of 5% and 3%, respectively, in U.S. EPA Method 3A [14].
As emission factors are often dependent on the type of material being burned and the method of burning, changes in composition and burn efficiency may change the emission factors determined herein.

Overall, the emissions from open burning of four MRE waste compositions and four MRE fiberboard packaging containers were quantified for a range of emission types. Fiberboard packaging containers for 12 MREs consisted of current and prospective container material (cardboard and polymer-coated for wet strength). All fiberboard packaging had low

PCDD/PCDF emission factors, consistent with values for a range of biomass types. The highest value, approximately three times higher than the other packaging types, was from the polymer-coated fiberboard packaging potentially due to minor changes in loss on drying, chloride, and sulfur content. A weak negative correlation with combustion efficiency was noted. PCDD/PCDF results from tests of four levels of old and new MRE packaging mixed in with the current fiberboard MRE containers increased levels up to six-fold from the containers alone. As well, emission factors amongst the MRE compositions varied six-fold with no obvious relation to composition.

Average PAH results from the fiberboard containers varied between 30 and 75 mg/kg fiberboard. Addition of the MRE compositions to the baseline fiberboard more than doubled these values. VOCs from burning fiberboard containers showed dominant benzene, acrolein, and toluene. The containers with the polymer coating had two of the highest VOC concentrations but this was related to low MCE values; all of the VOC emission factors were negatively correlated with MCE and two polymer coated containers showed low VOC emissions at high MCE. Addition of MREs to the baseline packaging fiberboard showed little change in emission factors from those of the packaging alone.

PM emissions were 90 % less than 1 µm for fiberboard tests and tended to follow the combustion process and release of CO and CO_2. Little distinction was noted between the PM emission factors for the four packaging types; no obvious relationship with MCE was observed. Addition of MRE pouches to the baseline fiberboard significantly increased the PM emission factors – approximately five- to six-fold.
In general, emissions tended to follow MCE – higher values of MCE associated with greater combustion efficiency led to lower emission factor values across all compositions tested. This suggests for this work that attention to promoting improved combustion, rather than efforts to alter waste composition, was a more effective means of lowering emissions.

6.10 Soldier Acceptance

MRE Boxes

- All Soldiers agreed the new corrugated box was harder to open compared to the current fiberboard box.
- Soldiers reuse MRE boxes for trash and ammo.
- Recycling boxes in the field was not currently an important consideration.
- Soldiers from the 82nd Airborne preferred the corrugated boxes due to their lighter weight (if they can be made easier to open). Soldiers from the 542nd did not have a preference for either of the MRE boxes or MRE bags.
- Likes:
    i. Corrugated box was more lightweight and has better structural integrity.
- Suggestions for Improvement:
    i. Make corrugated box easier to open (use less glue).

Figure 112. Sustainable Technologies for Ration Packaging Systems

82nd Airborne Focus Group (Ration Packaging):

The Soldiers first compared the current MRE box to a new corrugated MRE box. They were asked to share any differences they noticed between the boxes. The Soldiers' initial observations were that the new box may be more water resistant than the current MRE box, the new box was corrugated, and the new box was harder to open. All of the Soldiers agreed the new box was harder to open and said it was harder because it's thicker, has more glue, and they were unable to get their fingers underneath the box's flaps to pull the box open. The Soldiers also noticed that the new MRE box may be able to fit more MREs than the current box and said a dozen MREs per box was "perfect per box" and "perfect for patrol" because they would need three boxes per platoon. One Soldier then said he thought the new corrugated boxes would be harder to stack than the current boxes. Once the Soldiers were told about the weight difference of the boxes, most of the Soldiers agreed that the new box should be used due to its lighter weight, provided it can be made easier to open.

The Soldiers then discussed ways in which they reuse the current MRE boxes. Most of the Soldiers said they are primarily reused for trash or ammo boxes. One Soldier said he stacked some boxes and used them as a "foot locker" and to store socks. All of the Soldiers agreed that reusing the new corrugated box would "probably last longer" than the current MRE box because it has "better structural integrity."

Next, the Soldiers compared the current MRE bags to a new MRE bag. A majority of the Soldiers said the new MRE bag was easier to open, while two Soldiers said the current MRE bags were easier to open. When opening the bags, some Soldiers used their hands, some used their teeth, and some used knives. One Soldier said he would typically be able to open an MRE bag with his teeth, but was unable to open the new bag with his teeth. The Soldiers who thought the new bag was easier to open said it was because the clear packaging was “not as slick as the brown.” One Soldier then said the “best combination” would be the current MRE bag made clear because with a clear bag, “you can see what you’re getting.” Another Soldier said he would be concerned about opening the new MRE bag if it were wet and was also concerned about the new packaging getting brittle in cold or hot temperatures. Next, the Soldiers remarked that the new MRE bags are smaller, which they liked because they could fit more in their rucksacks. Some of the other Soldiers said that although it’s nice the bags are smaller, “it’s not going to make that big of a difference because we will field strip it.” One Soldier then said a benefit of the current MRE bag was they can reuse it once they field strip the MRE. They said once field stripped, they could fit 3-4 meals into a single MRE bag.

The Soldiers then discussed additional ways in which they reuse the current MRE bags. All of the Soldiers said they reused it at some point, mainly for trash or for medical emergencies (e.g. chest wounds). Due to the way the new MRE bags are sealed around the sides, some of the Soldiers peeled them open such that the top and both sides were opened. Because of this, they said the new MRE bag could not be reused in the same way because once opened, it cannot hold trash or other items unless only the top was torn. One Soldier who preferred the current MRE bags suggested vacuum sealing the current bags in the same way as the new bags are.

The Soldiers were then asked about whether they currently recycle MRE boxes. All of the Soldiers said they do not recycle the boxes and “don’t care if it’s recyclable” because when they are in the field, they “don’t deal with that end of it” and “if you live in the barracks, you throw everything in the same trash and no one cares.” The Soldiers then said “if you want me to recycle, it has to be as convenient as the garbage.” One Soldier then said at “Lewis, you can actually get credit [for recycling] and you can get fined if you have recycling in the trash.” Another Soldier said he “barely recycled in Germany and you’re supposed to.”

Lastly, the Soldiers provided their suggestions for improvement to the MRE packaging. These suggestions included using the new MRE boxes with the current MRE bags and perforating the new box liner to make the box easier to open. One Soldier said “if we access it [new box] from the bottom, it’s hard to rip it out from underneath. If it’s perforated, it’ll be easier to get free.” Another Soldier said “don’t get rid of the liner because I’d use it as a sleeping mat or as knee pad inserts.” Their other suggestions were to make the box easier to open by using less glue and labeling the side of the box that was glued or adding a “point-of-entry” label so a Soldier knows which side was easier to open.

6.10.1 542nd Quartermaster Focus Group (Ration Packaging):

The Soldiers first compared the current MRE box to a new corrugated MRE box. They were asked to share any differences they noticed between the boxes. The Soldiers’ initial observations were that the current fiberboard MRE box was heavier than the new corrugated box and the current box was more convenient and easier to open because it had less glue. When asked how the boxes would hold up to water, the Soldiers said it did not matter because the MREs inside "would be fine."

The Soldiers were then asked if they reuse the current MRE boxes. They said they primarily reuse the boxes for trash and ammo. The Soldiers then said both the current and new boxes could be reused for trash and ammo; however, the current fiberboard box would be better because the new corrugated box gets "ripped open" since it was more difficult to open.

Next, the Soldiers compared the current MRE bags to the new MRE bags. Many of the Soldiers used knives to open both the current and new bags. Some of the Soldiers said the current bag "was a pain," while others had difficulty opening the new MRE bags. All of the Soldiers noticed that the new MRE bags are smaller than the current, which they liked because it "saves on space" and they fit better in their uniform pockets. The Soldiers said it was "very much so a positive" that the new MRE bags fit more easily in their pockets because it makes them more easily accessible and was "easier than carrying a big brown bag in your pocket." All of the Soldiers said they do not field strip their MREs.

The Soldiers were then asked how they reuse the current MRE bags. They said they primarily use them for trash or for chewing tobacco. One Soldier also said "in a survival situation, you could collect water [with the MRE bag]." Overall, however, the Soldiers were not concerned about the reusability of the MRE bags.

When asked which boxes or MRE bags they prefer, none of the Soldiers had a preference because "as long as we're eating, we don't care." They were also not concerned about ease of opening because "everyone has a knife."

Lastly, the Soldiers were asked whether they recycle or burn the current MRE boxes. They said during a field exercise, they throw them away with other trash; however, they said while at the BCIL, they are thrown into the cardboard trash. The Soldiers said the importance of recycling in the field was "extremely low." The Soldiers said they typically do not burn their MRE boxes, but did not know the current fiberboard boxes contain wet strength additives that could potentially be harmful when burned.

6.10.2 Focus Group, Fort Carson, CO
166th Armor Unit
Tuesday the 19th of July 2016

The Focus Group was held in the field training area, near the food line after the dinner meal. The weather was clear. Occasionally, vehicles would drive by. A couple of Soldiers drifted in and out of the focus group, but a core group (10-12 people) remained for the entire session. A recording device was not available. Instead, comprehensive notes were taken by an observer.

New Packaging Alternative (script)

- "What experience do you have with MRE cases and straps?"

Prompts: carrying, shipping, throwing off of truck, opening.

• “Did you notice anything different about these boxes?”
Prompts: weight, size

• “Do you foresee any durability problems with the boxes.”
• “Recommendations for improvement to packaging material”
• “How easy/difficult to open?”
• “How do corrugated boxes compare overall to the current solid fiberboard boxes?”
• “Are the new boxes practical in an operational environment?”
“How do you transport MREs in an operational environment?”

• “Does the new box provide any benefits the current box does not?”
Overall likes and dislikes.
Recyclable

6.10.3 Outcome Summary

Summary: MRE boxes are transported on vehicles to the field. When in the field, they break down the boxes and distribute the MREs right away. They use the cases as chairs and tables. They cut down the cardboard insert to a smaller size to make Range cards.

After carrying the boxes a short distance, they noticed that the boxes were different sizes and that they labelling was different. They sat on the boxes, carried them, threw and kicked them around on the ground. The boxes did not open unless the straps were removed, then the flaps burst open. The group suggested more glue to help keep the flaps closed to be sure the boxes will not burst open.

Focus Group notes:
“What experience do you have with MRE cases and straps?” (Examples: carrying, shipping, throwing off of truck, opening.)
• Second wrap was irrelevant, creates more trash.
• Their Sergeant Major has a particular way he wants them to deal with this packaging and it created more waste for them to manage.
• How they handle the cases—they break down from case then distribute the MREs.

• They do not transport in cases for very long, break down right away.
• They use the cases as chairs and tables.
• They use the cardboard insert to write their Range cards on. With the current cases they cut the insert down to size.

The MRE cases were loaded in the back of an SUV. The participating Soldiers were asked to carry all the MRE cases out of the vehicle. Differences between the two types of cases, current and test, was not discussed at this point.
“Did you notice anything different about these boxes?”
• Carrying the cases out of the car
• Observation: about half used the straps and half used their hands to carry.
• Perhaps the gloves and fingers getting under the straps were affected.
• They noticed some differences in carrying them.

• Dimensions
• Labeling
• Some didn't notice anything.

The moderator explained that half are corrugated and are recyclable. The group discussed the new packaging, pros and cons, etc.
Pros-
• Smaller insert in test cases.
• Cardboard insert was a better size for reuse than the current longer pieces.
• Not allowed to have fires at their level, so the flammability was not relevant to them.
• Easier to open
    - Doesn't affect our mission to have easier/harder to open cases

• Dislike the longer insert in the current cases
• Would like a range card printed on the insert
• "Want anything else printed on them?" No, the range card was sufficient

• Better for the environment.
• "Lighter was better" when transported on the back of a vehicle

Cons-
• May be bad if the boxes can't handle being sat on.
• It would affect their mission if the boxes burst open in transit.

The moderator invited the Soldiers to handle the test cases as they would be by Soldiers in the field.
• Sitting: two sat on them the tall way and another the short way. The straps were still on all. The cases were adequate for sitting.
• Threw cases around
• Threw the cases straight up into the air and let hit the ground.
• Carried by straps and tugged at the straps so the weight of the case pulled at individual straps.

• Removed straps then kicked and threw the cases around again. Observed that the flaps opened.
• Comments
    • Maybe a little more glue would be needed for the test cases — "way weak".
    • Too weak when the box was thrown on the ground without the straps.
    • It would affect their mission if the boxes burst open in transit.

6.11 Assembly Evaluation
6.11.1 MRE Pretrial Assembly Demonstration at AmeriQual Packaging

February 12th-16th, 2013

6.11.1.1 Conclusions / Recommendations
Tasks for Assembly Trial

- Evaluate the compatibility of corrugated containers integrated into MRE assembly operations at AmeriQual Packaging during the assembly trial
- Assess compatibility with packaging assembly equipment to include case erector, case sealer, strapping equipment, ancillary assembly equipment, conveyors, palletizing equipment and stretch wrapping operations
- Assess performance of adhesives in bonding with top and bottom flaps of coated materials
- Evaluate packing compatibility of 2013 rations to include fit/function of fully packed cases
- Identify line inefficiencies and incompatibility of materials associated with new packaging
- Identify trends in packaging defects and identify root cause of product damage incurred during assembly operations
- Identify major integration risks and identify necessary equipment modifications prior to 15 pallet demonstration trail in 4Q FY13

6.11.1.2 Inspection notes from NSRDEC engineers and AmeriQual personnel: The inspection results below represent findings from the two pallets that were constructed at AmeriQual Packaging in February. A 100% inspection was conducted and totaled 96 containers or two full pallets.

Excessive Gaps: Several of the containers had excessive gaps between the top flaps (major flaps). The gap width varied in length and was more prevalent in the Case B containers. According to the ACR-M-033 "*The box shall be closed in accordance with closure method 2A1 of ASTM D1974/D1974M, Standard Practice for Methods of Closing, Sealing, and Reinforcing Fiberboard Boxes; except the gap between the outer flaps shall be not more the 3/4 inch wide." The primary cause may be from excessive bulging of the container, improper configuration of the 12 rations, case sealing equipment and interference of the minor flaps during case sealing operations.* Note that during the trial assembly of the two pallets, MRE 33 procurement rations were used to fill the containers. These samples are part of the new contract and normally take some time to learn how to configure the new components into the meal bag, it was assumed that later trials may show samples that are smaller in size and thus better configured into the container, possibly alleviating some of the bulging issues. The excessive gap was pictured in Figure 113 below.

Figure 113. Excessive gap width of ¾ inch or greater between the major flaps, normally caused by over-packing

Container Crushing: A number of the containers showed signs of crushing at the corners and end panels. The area of most damage was with the containers at the corners of the pallet where most of the material-handling impacts occur during handling and transportation. Damage also was prevalent at the bottom corner containers on the pallet. Damage from these containers was most likely from overhang on the pallet which was approximately 1.5 inches on two sides of the pallet load, the front to back overhang was minimal. Crushing damage to the container was shown in Figure 114.

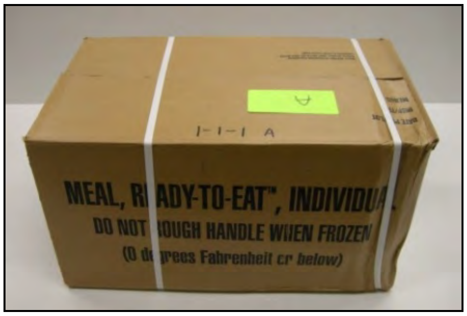


Figure 114. Crushing of the corrugated container during transit and or during material handling, pallet overhang was the primary cause of this type of damage

Misaligned Straps: During assembly the container strapping was offset on the container with one of the two straps nearly an inch away from edge. The prototype container was slightly larger than the existing solid fiberboard container and may have caused the strapping to be off center. Timing on the strapping equipment could potentially be adjusted to correct the issue. This problem is shown in Figure 115 below.

Figure 115. Misaligned straps due to the larger case size, issue can be corrected through adjustment of strapping systems

Minor Flaps Pushed Out: During assembly, the minor flaps were pushed out due to excessive bulging of the container. The issue was more prevalent on the Case A containers. This defect normally occurred when the major flaps were pushed together or touching, when this occurred the minor flaps would then be pushed out as the internal pressure from the over-packed rations would push them out. The type of defect was also common in the existing containers as well and varies by Case A or B. Pushing out of the side panels may show to reduce compression strength as the panels are not in their normal or ideal vertical position. This problem was shown in Figure 116.

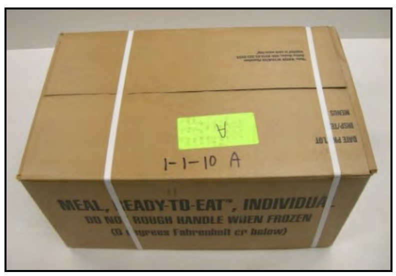


Figure 116. Minor flaps pushed out due to over-packing of corrugated case

Puncture in Container: Some of the containers showed punctures in the board materials with tears and holes in the containers. The defect was primarily from the case sealing equipment and could be corrected by making modifications to the sealing equipment to open up the equipment to accommodate a larger case size. Guide rails on the assembly line may also have led to some additional damage to the cases and would need to be modified to accommodate a new case size. Evidence of punctures was shown in Figure 117 below.

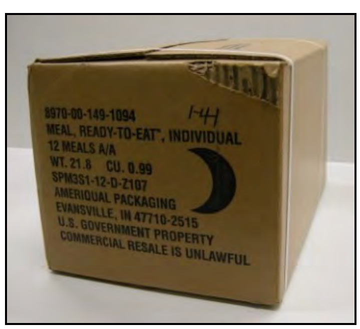


Figure 117. Superficial damage to container during material handling operations or damage from case assembly equipment

Bottom Crushing: The majority of the bottom containers had crushing at the bottom of the cases from the weight of the above containers and the overhang on the pallet. This type of defect was also common in the existing containers primarily due to pallet overhang. The damage was also most prevalent on the bottom corners of the pallet due to possible overhang on two edges of the container. Bottom crushing evidence was illustrated in Figure 118.

Figure 118. Crushing of the bottom containers that interface with the wooden pallet, overhang was often intensify this type of defect and may also negatively impact compression strength and unit load stability

False Scores on Top Flaps: Several of the prototype cases had false scores on the major flaps primarily due to interference from the minor flaps and or from rations protruding from the container due to over packing. This defect occurred more often on the Case B containers due to excessive bulging of the container. This defect could be corrected by improving packing procedures and adjusting equipment to compact rations more effectively. This type of defect was also common in the existing containers and varies between Cases A and B. Figure 119 shows the false scores as described above.

Figure 119. False scores on major flap caused by over-packing of container

Glue Bonding on Top / Bottom Flaps: In the majority of cases, the top flaps were not sealed. The hot melt adhesive did not penetrate the coated liner in time to bond to the combined board. This defect could possibly be corrected by allowing longer time for the glue to penetrate the coating and bond to the coated board. Also, overpressure from rollers could possibly be extended to keep the flaps together for a longer period of time. The bottom flaps had good bonding with the hot melt adhesive which most likely had more time to set and bond to the coated board. To correct this defect, the hot melt adhesive may need to be modified or another type may need to be used in order to match the case sealing operations. The failure of the adhesive was depicted in Figure 120 below.

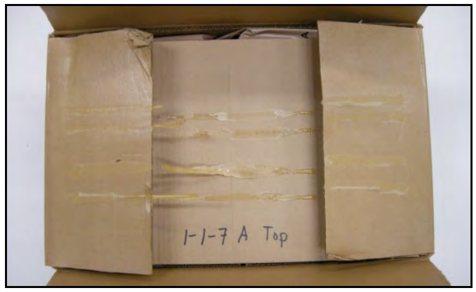


Figure 120. Adhesive failure on the top flaps during the assembly trial run

From pallet 1, 8 types of defects were found within the sample set and included: excessive gaps, container crushing, misaligned straps, minor flaps pushed out, puncture in containers, bottom crushing, false scores on the top flaps and glue bonding issues on the top flaps of the containers. The majority of the defects were from the assembly process equipment and handling operations during packing and transport. Equipment modifications may have to be completed in order to accommodate the larger case sizes to include rail/conveyor modifications, glue modifications, adjustments to strapping equipment both at the case level and pallet level and adjustments to case erecting / sealing activities.

Similar to pallet 1, pallet 2, contained 8 types of defects within the sample set including: excessive gaps, container crushing, misaligned straps, minor flaps pushed out, puncture in containers, bottom crushing, false scores on the top flaps and glue bonding issues on the top flaps of the containers. The defects were similar in type/frequency as in the first pallet of MRE cases. The majority of the defects were from the assembly process equipment and handling operations during packing and transport. Equipment modifications may have to be completed in order to accommodate the larger case sizes to include rail/conveyor modifications, glue modifications, adjustments to strapping equipment both at the case level and pallet level and adjustments to case erecting / sealing activities. Please note that the defects shown here are also common in the existing solid fiberboard containers and normal assembly process but may occur less frequently due to proper set up and compatibility of equipment. Presented in Figure 121 was a bar graph illustrating the percent of defects in the pallets caused by excessive gap width.

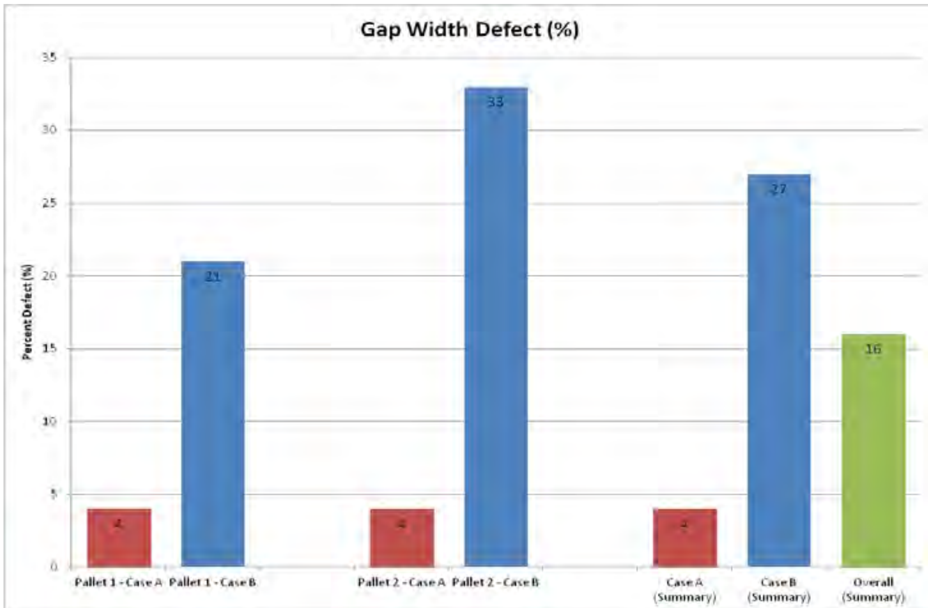


Figure 121. Percent defect based on excessive gap width (containers with 0.75 inch or greater gap between the major flaps are failed)

The assembly pre-trial was able to integrate the new containers into the assembly line and fully pack out 96 containers for follow-on inspections. The pre-trial was able to identify issues with the gluing and case sealing operations and properly identified fit issues with the equipment and railing section of the conveyors. Future trials seek to correct incompatibility issues and improve packing line speed to maintain proper case filling operating levels of approximately 22 cases per minute. It was also recognized that the rations for case be seemed to be oversized and caused the containers to bulge excessively and subsequently caused excessive gaps in approximately 33% of containers. Below was a list of integration challenges that need to be proven in the actual manufacturing environment during follow-on manufacturing trials.

Assembly Line Compatibility Issues:

- Utilize Pearson CE35 automatic case erector to form containers
- Modify railing section to accommodate larger case size (convert to adjustable railing)
- Widen Klippenstein SK500HM machine to accept new wider box
- Lower complete plow/ flap breaker assembly at front of Klippenstein SK500HM
- Manufacture new photo eye brackets because of lowering plow flap breaker assembly
- Change program to allow for slower set time and transfer
- Identify hot melt adhesive for both top and bottom case sealer
- Change the glue dwell time from .65 to 265 to allow proper setup time
- Lower the compression station to allow proper compression
- Extend top rollers to extend compression time during hot melt curing
- Modify / replace ink substrate for printing onto coated material
- Adjust settings on strapping units
- Adjust pressure settings on case mixing equipment to minimize crushing of containers
- Adjust labeling equipment to accommodate new case size
- Adjust top cap for unitized load to accommodate new pallet footprint

- Adjust setting of unit strapping equipment to accommodate new pallet size (optimize both placement of strapping and pressure settings
- Modify major flaps to have a gap of 1/8 inch
- Modify print layout to accommodate new container size and orientation of panels
- Change flute direction of corrugated top pad

Figure 122. TISA Operator moving ESTCP pallets for inspection.

Figure 123. Work Station and both pallets for full inspection.

Figure 124. Damage to Pallet #2

Figure 125. Pallet #2 Layer 2 Box 1

Figure 126. Pallet #1 Layer 2 Box 10 damage.

Figure 127. Damage to Pallet #1 Layer 2 Box 10

Figure 128. Dents on Pallet #1 Layer 2 Box 10

6.12 Survey of Assemblers – AmeriQual and Wornick

1. What do you like about the corrugated container?
    a. AQ Response – the box was a little lighter and more flexible.
    b. W Response - Really good fiber tear while reworking cases, much lighter.
2. What don't you like?
    a. AQ Response – the box was more prone to being damaged through the assembly process, more so than the current box. The coating will require alternate type of ink for printing of the required information at the assembly plants.
    b. W Response - Lack of tackiness, very frail compared to the fiberboard counterpart. Requires non porous ink to print on. More prone to damage from machinery.
3. Can this be adapted to your production line?
    a. AQ Response - It can be
    b. W Response - Yes
4. Could this gain acceptability on your production line?
    a. AQ Response – it probably can after considerable adjustment to all facets of the equipment currently in place. Since the current box was so rigid, the equipment was set for that and would have to be totally re-calibrated to exert LESS pressure etc. to the corrugated box.
    b. W Response - Yes, corners and flaps are within spec.
5. If cost was less than current fiberboard container, would that be a deciding factor:
    a. AQ Response – only if the only difference was price, there would still have to be similar quality and performance before price would be the only deciding factor.
    b. Yes
6. How was the filling and packing with these containers?
    a. AQ Response – it was slow during this process for the test due to small runs and the fact that we were packing current bags in an interior case size that was smaller than our current MRE box.

    b. W Response - Same as fiberboard shippers.

7. How does it compare to current solid fiberboard container?
    a. AQ Response – our initial impression was that it was not as sturdy and therefore we were doubtful of its durability throughout the process, in storage and in the field.
    b. W Response - Lighter, more prone to damage
8. Any comments on the glue?
    a. AQ Response – there had to be special procurement of a glue that would adhere to the box since it has the special coating. Any specialty item that has to be purchased potentially increases the cost and the flexibility if that specialty item was not widely available.
9. Any comments on the printing?
    a. AQ Response - there had to be special procurement of an ink that would adhere to the box since it has the special coating. Any specialty item that has to be purchased potentially increases the cost and the flexibility if that specialty item was not widely available.
    b. W Response - Requires non porous ink, would have to flush video jet out for change over's (TOTM, MCW, HDR, MARC), maintenance could get pricing on porous vs. non porous and possibly remain using non porous.
10. Did the containers pass end item inspection?
    a. AQ Response – There were some of the end item tests in the original test that did not pass because the bottom flaps did not hold nor did the flaps exhibit fiber tear when opened. I think that on a subsequent run, the glue was adjusted and did correct that issue (see number 8)
11. Did you issue a certificate of conformance for the Army Veterinary Food Inspection Specialist Board to review?
    a. AQ Response – does this mean the Army Veterinary Food Inspection Specialist Inspectors? If so, then no.
12. Any other feedback?
    a. AQ Response – not at this time.
    b. W Response - Seams are at risk of bursting even with light compression, occurred 3 times out of 50 boxes.

       - Cases are prone to sliding when stacked on each other, more so than fiberboard type shipper, we would counter this by adding a middle slip sheet, which increases cost.

       - Liners provided are an inch longer than ours, which resulted in 14 cases not closing properly and having to be reworked, liner would prevent back flap from folding inward when the kicker would function properly.

       - Score marks for all flaps need to be slightly deeper to assist with our method of closing the flaps and reduce rework.

       - When attempting to run a few samples through the case erector each one jammed during the glue compression stage, 5 total attempts. Maintenance was suggesting 2-3 hours for adjustments on the case erector. After failed attempts with the case erector we hand glued one shipper and packed 12 A meals into it, the durability of this shipper was being put to the test through our case erector. Side seams bursting during compression and top flaps came up way short of spec, not bad for a first attempt though.

Finding a suitable amount of pressure to allow the case to close properly without bursting the sides of the box may be a challenge. Would this be an issue if we assembled these on an off day to allow for thorough troubleshooting and analysis versus at the end of a production day?
-Durability a question through our case sealer (mainly compression).
-Code, RFID, and TTI label placement, these shippers have all the print in different locations compared to our current shipper.
-Have yet to test these through the robot, layer table will be a concern since these boxes lack tackiness and are prone to sliding.
- Stacking of pallets and movement inside the accumulator, cases falling inside the cage and while traveling back into the robot for completion of pallets.
-Amount of loss during test, we are unsure of how many will be wasted during adjustments.

7.0 COST ASSESSMENT

7.1 COST MODEL

Here was the cost for the coated paper.

- Coating = $12.95 MSF
- Paper = $16.25 MSF
- Shipping (will vary greatly depending on where we source) into Northeast = $1.50 MSF
- TOTAL = $31.00 MSF for the coated paper.

The cost model fluctuates with the cost of the paper.

7.2 COST ANALYSIS AND COMPARISON

The cost of the solid fiberboard container was approximately the same as the coated corrugated container. $1.25

8.0 IMPLEMENTATION ISSUES

This technology could be implemented fairly quickly for manufacturing as well as for assembly at the Army co-packers. There does not appear to be any environmental or worker safety regulations, current or proposed that impacts the transition of the alternate the alternative technology.

There was not really any major procurement issues as a corrugator would be contracted to fabricate the containers. There was only the change of equipment for the glue dispenser that would be a commercial-off-the-shelf [COTS] item. The production of the containers would be an easy transition and there will be no scale-up issues since this ESTCP project already proved that a corrugator can make these containers easily. The technology was customized by optimizing a coating in chemical structure and thickness to provided strength and meet military performance specifications. There are not any proprietary or intellectual property rights issues associated with the technology. A patent of the coating structure and container design did not get approved.

Technology transfer efforts will include the demonstration for the STO-D and the presentation to CFD and JSORF after conclusion of the demonstration. Also, there was potential opportunities for technology transfer to other military agencies and services as everyone needs shipping and packing containers.

JSORF has concurred to have the corrugated container transitioned to the Warfighter. NSRDEC will work with the assemblers for the implementation.

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APPENDICES

Appendix A: POINTS OF CONTACT

APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone E-mail	Role in Project
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Ms. Shari Dangel	NSRDEC, Combat Feeding Directorate 10 General Greene Ave, Natick, MA 01760	508-233-4573 Shari.r.dangel.civ@mail.mil	Transportation and air drop inspector
Mr. Joe Quigley	NSRDEC, Combat Feeding Directorate 10 General Greene Ave, Natick, MA 01760	508-233-5860 Josph.j.quigley6.civ@mail.mil	Data analysis
Mr. Scott Martin	NSRDEC, Air Drop Directorate, 0 General Greene Ave, Natick, MA 01760	508-233-5048 Scott.c.martin.civ@m ail.mil	Air Drop
Mr. Jade Vardeman	Moses Biologic, LLC	Vardeman99@yahoo.com	Insect Infestation
Dr. Brian Gullett / Dr. Johann	U.S. EPA 109 T.W. Alexander Drive, Research Triangle Park, NC 27711	919-541-1534 Gullett.Brian@epa.gov	Emission Testing
Ms. Robin Altmeryer/ Mr. Brian	AmeriQual Packaging 225 West Morgan Ave. Evansville In 47710	812-421-4876 raltmeyer@ameriqual.com	MRE Assembly Trial
Mr. Greg Geil Mr. Ron Walling	Advanced Materials Center 125 Swanson Street, Ottawa, Illinois 61350	815-433-1495 ggeil84@aol.com	Biodegradation Certification
Shawn Mortimore	Western Michigan Univiversity 4651 Campus Dr. Kalamazoo, MI 49008	269-276-3532 shawn.mortimore@wmich.edu	Biber Board Association Certification for Recyclability
Mr Jim Watson	York Containers 138 Mt. Zion Road, Yrok, PA 17402	800-772-9675 Jim Watson jwatson@yorkcontainer.com	Corrugator
Mr. Zach Eckhart	Spectra-Kote	240.344.0068 zeckert@spectra-kote.com	Paper Coating
Ms. Patricia Curran Ms. Sarah Gedrich Mr. Ryan	LOGSA Packaging, Storage & Containerization Center, Tobyhanna, PA	570-615-7756 Patricia.curran.civ@mail.mil	Packaging Performance Testing