ESTCP
Cost and Performance Report

(WP-200816)

Nanotechnology for the Solid Waste Reduction of Military Food Packaging

June 2016

This document has been cleared for public release; Distribution Statement A

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01/06/2016

2. REPORT TYPE
Cost and Performance Report

3. DATES COVERED *(From - To)*
04/01/2008 - 01/01/2015

4. TITLE AND SUBTITLE
Nanotechnology for the Solid Waste Reduction of Military Food Packaging

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jo Ann Ratto, Jeanne Lucciarini, Alan Wright, Jason Niedzwiecki,
Claire Lee - U.S. Army Natick Soldier Research, Development and Engineering Center

Robin Altmeyer - AmeriQual

5d. PROJECT NUMBER
WP-200816

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Natick Soldier Research, Development and Engineering Center
15 Kansas Street
Natick, MA 01760

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program Program Office
4800 Mark Center Drive
Suite 17D03
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
ESTCP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
This report describes the evaluation demonstration/validation project of new nanocomposite packaging for the military by the Natick Soldier Research, Development, and Engineering Center (NSRDEC), which was supported by the Environmental Security Technology Certification Program (ESTCP). The materials that were evaluated were developed via the earlier NSRDEC Environmental Quality Basic Research (EQBR) and the NSRDEC Strategic Environmental Research and Development Program (SERDP), as well as industry-based efforts in the area of nanocomposite packaging films that have matured into commercially available products.

15. SUBJECT TERMS
Nanocomposite packaging , Meal, Ready-to-Eat (MRE), Micro-wave Assisted Thermal Sterilization (MATS), solid waste reduction.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Jo Ann Ratto
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	UU	UL	46	508-233-5315

Page Intentionally Left Blank

Page Intentionally Left Blank

COST & PERFORMANCE REPORT

Project: 200816

TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION 1

1.1 BACKGROUND 1

1.2 OBJECTIVES OF THE DEMONSTRATION 1

1.3 REGULATORY DRIVERS 1

2.0 DEMONSTRATION TECHNOLOGY 3

2.1 TECHNOLOGY DESCRIPTION 3

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 6

3.0 PERFORMANCE OBJECTIVES 7

3.1 OVERALL MRE SYSTEM PERFORMANCE OBJECTIVES 8

4.0 SITE/PLATFORM DESCRIPTION 9

4.1 TEST PLATFORMS/FACILITIES 9

4.1.1 NSRDEC 9

4.1.2 Insect Testing 9

4.1.3 Assembler 9

4.1.4 Field Test 9

4.1.5 Transportation/Distribution 10

4.1.6 Air Drop 10

4.2 PRESENT OPERATIONS 10

4.3 SITE-RELATED PERMITS AND REGULATIONS 10

5.0 TEST DESIGN 11

5.1 ASSURANCE OF FOOD SAFETY 11

5.1.1 Microbial Validation 11

5.1.2 Water Content/Water Activity 11

5.1.3 Lipid Oxidation 11

5.1.4 Burst Test 11

5.1.5 Oxygen Concentration 12

5.1.6 Acceptance of Food from Sensory Panel 12

5.1.7 High Velocity 12

5.1.8 Delivery 13

6.0 PERFORMANCE ASSESSMENT 15

6.1.1 Microbial Validation 15

6.1.2 Water Content/Water Activity 15

6.1.3 Lipid Oxidation 16

TABLE OF CONTENTS (Continued)

Page

6.1.4 Sensory Analyses 16
6.1.5 Assurance of Recyclability of Meal Bag 18
6.1.6 Insect Infestation 18
6.1.7 Integrity of Meal Bag from Rough Handling 18
6.1.8 Retort Pouch 19
6.1.9 Field Test Results 20
6.1.10 Reduction of Solid Waste 20
6.1.11 Cross Country Shipment and Cold Weather Storage – Fort Richardson 21
7.0 COST ASSESSMENT 23
7.1 COST MODEL 23
7.1.1 Processing and Pouch Formation Costs 23
7.1.2 Resin (Polymer) For Manufacturing 24
7.1.3 Filling/Sealing Process of Food Pouches 24
7.1.4 Disposal Costs 24
7.1.5 Shipping and Handling Costs 24
7.1.6 Soldier Training 24
7.2 COST ANALYSIS AND COMPARISON 24
8.0 IMPLEMENTATION ISSUES 27
9.0 REFERENCES 29
APPENDIX A POINTS OF CONTACT A-1

LIST OF FIGURES

Page

Figure 1. Nanocomposite Morphology 3

Figure 2. Tortuous Path Model 4

Figure 3. Current Packaging Structure of the MRE 4

Figure 4. High Velocity Unit Load Configuration (Five Layers of Honeycomb) 13

Figure 5. Drop Sequence for Aerial Delivery 13

Figure 6. Pallets of MREs for ESTCP Program 15

Figure 7. Sensory Studies of Pretzels in Non-retort Pouch at 36 Months. (MRE Package and Nano Pouch) 17

Figure 8. Sensory Studies of Penne Pasta in Retort Pouch at 36 Months. (MRE Control and Nanocomposite) (GL-KN) 17

Figure 9. Drop Tester 19

Figure 10. Size and Weight Comparisons of the MRE Packaging Components to Include the Meal Bag, Retort Pouch, and Non-Retort Pouch 21

LIST OF TABLES

Page

Table 1. MRE Non-Retort and Retort Pouch Materials 5

Table 2. MRE Non-Retort Pouch Structure 5

Table 3. MRE Retort Pouch Structure 5

Table 4. Performance Objective – Meal Bag, Non-Retort, Retort Pouch 7

Table 5: Overall Performance Objectives 8

Table 6. Defect Summary of Samples 19

Table 7. Field Study Question: Acceptability (Liking) 20

Table 8. Cost Variation as a Function of Number of Polymer Layers 23

Table 9. Products for Accelerated Storage Study 28

ACRONYMS AND ABBREVIATIONS

ºC	Degrees Celsius
°F	Degrees Fahrenheit
Å	Angstroms
A_c	Area if the circular cutout
ANOVA	Analysis of Variance
ANSI	American National Standards Institute
A_p	Area of the package
cc	Cubic Centimeter
CFD	Combat Feeding Directorate
CFREP	Combat Feeding Research and Engineering Program
DLA	Defense Logistics Agency
DoD	Department of Defense
EQBR	Environmental Quality Basic Research
EPA	United States Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FEST	Food Engineering and Science Team
FOC	Force Operating Capabilities
ft.	Feet
g	Grams
GC/MS	Gas Chromatograph/Mass Spectroscopy
HSD	Honest Significant Difference
JSLIST	Joint Service Lightweight Integrated Suit Technology
JSORF	Joint Service Operational Ration Forum
km	Kilometer
lb.	Pound
LDPE	Low-Density Polyethylene
M.	Meter
m.	meter
MATS	Microwave Assisted Thermal Sterilization
MBL	Moses Biologic
mil	thousands of an inch
MIL-PRF	Military Performance
MLS	Montmorillonite Layered Silicate

MRE	Meal, Ready-To-Eat
MSI	Thousands square inches
nm	nanometer
NSRDEC	Natick Soldier Research, Development and Engineering Center
OSHA	Occupational Safety and Health Association
PE	Polyethylene
PI	Principle Investigator
ply	layer
SD	Standard deviation
SERDP	Strategic Environmental Research and Development Program
SIMS	Sensory Quality Panel Software Systems
SPME	Solid phase microextraction
sq. mi	Square mile
TRADOC	Training and Doctrine Command
VETCOM	Veterinary Command
W_c	Weight of the circular cutout
W_p	Weight of package
YPG	Yuma Proving Ground

ACKNOWLEDGEMENTS

The Principal Investigators (PIs) acknowledge the Environmental Security Technology Certification Program (ESTCP) as well as all the collaborators and partners in this project. This demonstration/validation program was not only successful for nanocomposite packaging, but a rewarding and valuable experience for the PIs. The PIs began exploring nanocomposites with basic research over 10 years ago and ultimately transitioned the technology to the ESTCP program. The nanocomposite effort began with support from a 6.1 Environmental Quality Basic Research Program that transitioned to a 6.2 Strategic Environmental Research and Development Program, then to a 6.3 Army Research Laboratory Pollution Prevention Program, then finally to the ESTCP. The authors are truly grateful for all the funding and support for 6.1 to 6.4 work utilizing nanotechnology packaging. The PIs have been dedicated to these efforts, and it is anticipated that this technology will be used someday by the Warfighter.

In particular, the PIs thank Dr. Robin Nissan, Mr. Bruce Sartwell, Dr. John Hall, and Dr. Jeffrey Marqusee as well as their support teams and their review boards, all of whom have given valuable input and feedback throughout the program. Also, the PIs are forever grateful for the financial support of the project from ESTCP.

In addition, many scientists and engineers participated in this effort and formed a dedicated team. All the members brought their own expertise to execute their portions of the demonstration/ validation plan. The Advanced Materials Engineering Team at the U.S. Army Natick Soldier Research, Development, and Engineering Center (NSRDEC) have all contributed to this project, especially Dr. Christopher Thellen and Ms. Danielle Froio. NSRDEC thanks Kuraray America Inc. for the nanocomposite food pouches; Cadillac Products Packaging Company for the nanocomposite meal bags; AmeriQual, especially Ms. Robin Altmeyer, for the assembly, quality control testing of the rations, and shipping of the pallets to a variety of locations. The team thanks Ms. Claire Lee and Ms. Nicole Favreau of the Combat Feeding Directorate, who performed the microbial evaluation and lipid oxidation, respectively. The team extends gratitude to Mr. Alan Wright and his team for the sensory testing and evaluations. The team is thankful to the air drop team at NSRDEC which consisted of Richard Benny, Brian Bagdonovitch, and Dale Tabor. The team appreciates participants of the field study evaluation, Ms. Wendy Johnson, Mr. Dan Harshman, Mr. Gregory Pigeon, and Mr. Scott Winroth. The team also acknowledges Fort Richardson and Fort Bliss for the transportation and distribution studies. Jade Vardeman of Moses Biologic is also recognized for conducting the insect infestations studies, and Pira International for their distribution laboratory testing. Everyone worked extremely hard in support of this ESTCP effort, and the team is forever indebted to each person for their talents and dedication.

Page Intentionally Left Blank

EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

As part of the Environmental Security Technology Certification Program (ESTCP), Natick Soldier Research, Development, and Engineering Center (NSRDEC) evaluated nanocomposite packaging for Meals, Ready to Eat (MRE) rations to demonstrate and prove the validity of the packaging systems' ability to decrease the amount of solid waste produced by the military. The packaging was developed during previous projects under NSRDEC's Environmental Quality Basic Research (EQBR) and Strategic Environmental Research and Development Program (SERDP). The film processing and manufacturing of the pouches were conducted on conventional processing equipment at AmeriQual Packaging. The assembly operation occurred smoothly without any problems or delays. Performance objectives for shelf life, rough handling, insect infestation, recyclability, and storage were evaluated. This investigation focused on three MRE components: the Meal Bag, the non-retort food pouch, and the retort pouch. The non-retort food item chosen for the storage studies was pretzels and the retort food item was vegetarian penne pasta. Storage studies were conducted for three years at 40, 80, 100 and 120 ^{o}F. Storage study testing consisted of: sensory analysis, oxygen concentration, hexanal analysis, and microbiological analysis.

TECHNOLOGY DESCRIPTION / DEMONSTRATION RESULTS

The nanocomposite Meal Bag was fabricated from the same base resin as the existing control bag, but 7.5% nanoparticles was added for improved thermal and barrier properties. The thickness of the nanocomposite Meal Bags was 7 mil versus 11 mil for the control bag. After testing and evaluation, it was determined that the performance objectives for the Meal Bag were all met. The nanocomposite Meal Bag's integrity in comparison to the control Meal Bag was in the same acceptable range. This was measured by determining the seal strength at the top and bottom seals. The Meal Bags were also rough handled at different temperatures using tests corresponding to the military specification requirements, and met the success criteria. Rough handling of the pallet load was also performed and minimal defects were found in both the control and nanocomposite Meal Bags. Another performance objective that the Meal Bags met was resistance to insect infestation. The control and nanocomposite Meal Bags were exposed to a variety of insects typically encountered during storage and samples were examined at predetermined time periods. There was no more than 20% failure for the Meal Bags. One of the performance objectives was to assure recyclability of the Meal Bag. This was demonstrated in the laboratory by remelting and reprocessing the polymer nanocomposite with other virgin polymers. Also, the recycling company, TREX, confirmed that the Meal Bags could be utilized in their recycling facility. TREX also addressed color, rheology, and mixing of the Meal Bag material with TREX's regrind. The weight savings, reduction of solid waste, and decrease in base resin are all approximately 30%; however, the addition of nanoparticles results in an increase in cost of the formulation.

For the retort and non-retort pouches, polymeric structures were used that had another protective layer for an oxygen barrier incorporated into the outer layer and also contained a nanocomposite layer. All tests were conducted with the control and nanocomposite pouches, except a microbial evaluation was added to retort pouch samples. All the tests passed except for the recyclability. The microbial evaluation was conducted at time 0 and for every storage interval that a sensory test was conducted during both the accelerated and long term storage. The microbial evaluation was performed with five retort pouches of each sample and all samples were acceptable with no food safety issues. During recyclability testing, it was determined that the wide range of melt temperatures of the polymers in the non-retort and retort pouches would prevent recyclability. Despite the pouches not being recyclable, they are potentially lighter in weight and could still be placed into a waste-to-energy converter which would be environmentally advantageous.

A critical performance objective was soldier acceptance of the packaging, which was demonstrated by a field study survey with approximately 100 soldiers. The acceptability of the packaging was comparable with the controls.

The reduction of solid waste was contributed to by the decrease in resin used to manufacture the Meal Bag. The reduction of solid waste for the retort and non-retort pouches is not significant because neither can be recycled, but there is a weight savings. The MRE food in the new nanocomposite packaging survived the airdrop even though the packaging had some defects. The inspection of defects on the nanocomposite packaging after the air drop and transportation studies was also successful with results comparable to the controls. The sensory panels conducted over the three year storage study had mostly favorable scores for the nanocomposite pouches in comparison to the controls.

IMPLEMENTATION ISSUES

Since the military is moving toward Microwave Assisted Thermal Sterilization (MATS) methods, and foil structures cannot be utilized with MATS, the nanocomposite structures offer an alternative to the foil barrier layers found in the control non-retort pouch. MATS is a direct heating method that offers faster thermal penetration and better uniformity than conventional retorting or canning. Food is subject to high-temperature, short duration treatment, allowing microwaves to penetrate the food, cooking packaged foods from the inside out and preventing burning around the edges. Preliminary studies have shown that these nanocomposite structures can successfully undergo MATS.

This project was presented to the Joint Service Operational Ratios Forum (JSORF) twice as informational briefings (2010 and 2012) and now work continues with support from the Combat Feeding Directorate (CFD) for project “Barrier Coatings for Optimized Package Performance”, which is performing accelerated storage studies at 100 °C for other food items for retort and MATS sterilization. Overall, the nanocomposite packaging has been demonstrated to be comparable in performance to the current control packaging with a reduction in solid waste and hopefully this technology will transition to the Warfighter.

1.0 INTRODUCTION

This report describes the evaluation demonstration/validation project of new nanocomposite packaging for the military by the Natick Soldier Research, Development, and Engineering Center (NSRDEC), which was supported by the Environmental Security Technology Certification Program (ESTCP). The materials that were evaluated were developed via the earlier NSRDEC Environmental Quality Basic Research (EQBR) and the NSRDEC Strategic Environmental Research and Development Program (SERDP), as well as industry-based efforts in the area of nanocomposite packaging films that have matured into commercially available products. Nanocomposite packaging for the Meal, Ready to Eat (MRE) Meal Bag, non-retort pouches, and retort pouches were developed with the goal of reducing Department of Defense (DoD) specific waste problems by the use of lighter-weight and recyclable military ration packaging that also meets combat ration operational requirements. The goal was to transition mature technology to material converters and demonstrate manufacturability and durability of nanocomposite packaging structures within the military logistics system. This investigation consisted of laboratory evaluations and field tests of various performance objectives for each of the three MRE packages, as well as overall performance objectives. Both the laboratory and field tests were performed in various locations and by various organizations in order to determine the efficiency of the nanocomposite MRE packaging as compared to the currently fielded control MRE packaging. Cost analyses were also performed.

1.1 BACKGROUND

The environmental problem of solid waste generated by the Army is being addressed in this demonstration/validation program. The amount of packaging waste generated per MRE meal is 0.36 lb. (22.9 % of total weight of ration). Based on the procurement of 40 million MREs, approximately 7200 tons of MRE packaging waste is generated every year. Deployed forces and contingency operations generate tons of solid waste that must be burned or backhauled to disposal sites at great expense. This coupled with the rising costs of packaging materials and disposal has dramatically increased the need to investigate alternative materials for combat ration packaging applications.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this effort is to demonstrate and validate new nanocomposite packaging for the military. Nanocomposite packaging for the Meal Bag, non-retort, and retort pouches will be demonstrated and validated to reduce DoD-specific waste problems by the development of lighter-weight and recyclable military ration packaging which also meets combat ration operational requirements. The goal is to transition mature technology to material converters and demonstrate manufacturability and durability of nanocomposite packaging structures within the military logistics system.

1.3 REGULATORY DRIVERS

This technology demonstration addressed Draft FY07 Army Environmental Requirements and Technology Assessment Document dated February 2007 and specifically addressed Requirement PP-5-06-01 “Zero Footprint Base Camps” which included elements of the previous Requirement, 3.5.c, “Solid Waste Reduction”, a top-ranked pollution prevention requirement. This program supported the following Training and Doctrine Command (TRADOC) Pamphlet 525-66, Military Operations, Force Operating Capabilities (FOCs): FOC-09-01 Sustainability, by achieving reductions in logistics demand and footprint; FOC-09-03 Power and Energy, by investigating technologies that showed promise in replacing fossil fuels for packaging applications; and FOC 11-01 Human Engineering, by reducing Soldier dismounted movement approach load to 40 lb. and dismounted Soldier's fighting load to 15 lb. This project also supports the Army Strategy for the Environment and Joint Vision 2020 doctrine by helping to bridge the gap between current and future joint capabilities, and by identifying new ways of exploiting emerging technological advances. It also contributed to simplifying deployment procedures, reducing weight of supplies, and minimizing environmental footprints.

Nanocomposite materials such as organically modified layered silicates are a novel way to optimize and improve polymer properties for high barrier packaging for military rations. Polymers have been filled with compatible nanoparticles to improve mechanical properties such as tensile strength and toughness, to slow diffusion to gases and moisture, and to impart dimensional stability at high temperature operations. Each nanoparticle is approximately 1 nm (10^{-9}m) in thickness and 100-500 nm in length. Owing to their ultra-fine feature size and very high surface area (750 m^2/g), these filler particles convey improvements in properties without adversely affecting the processability of the polymer (i.e., viscosity), as is characteristic with conventional macroscopic fillers. When dispersed throughout the polymer and oriented properly, the nanoparticles align to form a physical barrier that slows down the diffusion of gases through the polymer by formation of a tortuous diffusion path. This leads to significant improvement in oxygen and water vapor barrier properties which is essential for the extended shelf life of military rations. Nanocomposite Meal Bags, non-retort pouches, and retort pouches were produced commercially with MRE food, and assembled into pallets of MRE cases. This packaging underwent a variety of testing to demonstrate and validate it for future military use. These tests included: sensory, storage study, rough handling, distribution/transportation, and insect infestation.

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The nanocomposites which are targeted for the MRE Meal Bag, non-retort, and retort pouches have shown significant improvements in barrier properties to the current Meal Bag, as well as mechanical properties such as tensile strength and Young's modulus.

For packaging applications, nanocomposites have been shown to yield large improvements in barrier properties, as well as in physical properties such as tensile strength, tensile modulus (values obtained from stress/strain curve), and heat distortion temperature[1,2,3]. A key factor in determining the ultimate improvement in properties is the compatibility of the polymer/ nanoparticle and the dispersion of the layered silicate particles within the polymer matrix. The nanoparticle typically used is organically modified montmorillonite layered silicate (MLS), a mica-type silicate, which consists of sheets arranged in a layered structure.

MLS is used due to its high cation exchange capacity and its high surface area, approximately 750 m^2/g and large aspect ratio (larger than 50) with a platelet thickness of 10Å (angstroms)[4]. As shown in Figure 1, a conventional composite consists of two distinct phases, the polymer and the nanoplatelet, with minimal interface between them. Intercalation occurs when a small amount of polymer moves into the gallery spacing between the MLS platelets, causing less than 20-30Å separation between the platelets. This results in a well-ordered multilayer, with alternating polymer/clay layers. Exfoliation occurs when the clay platelets become further separated by the polymer chains. The separation distance can be from 80-100Å, which results in a well-dispersed nanocomposite with the potential of enhancing the mechanical, thermal, and barrier properties.

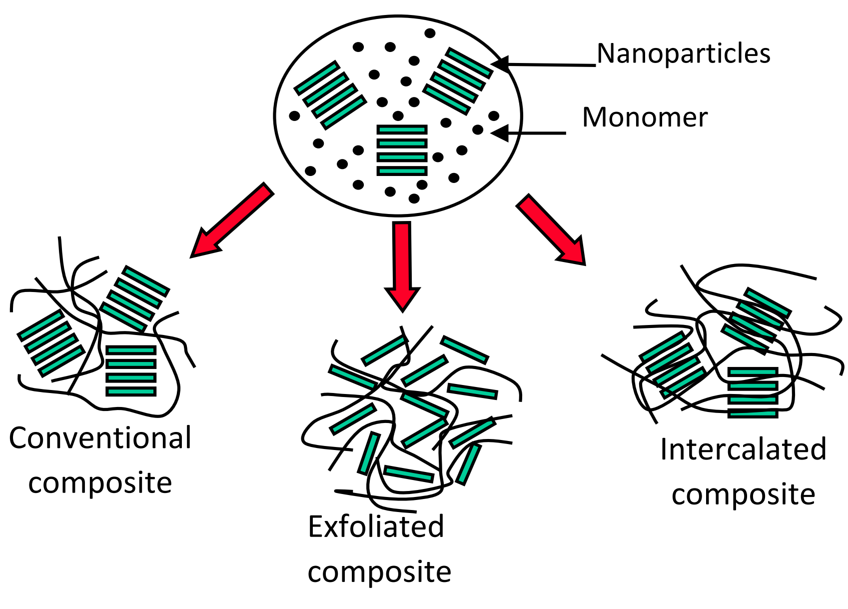

Figure 1. Nanocomposite Morphology

The dramatic reduction in permeability has been attributed in part to the presence of well-dispersed, large aspect ratio silicate layers, which cause solutes to follow a tortuous path. As shown in Figure 2, these results are in much larger effective diffusion distances, thereby lowering permeability. It has also been suggested that the presence of nanoparticles, with a very high surface area to volume ratio, significantly modifies the dynamic behavior of the polymer chains, leading to the observed property changes[1].

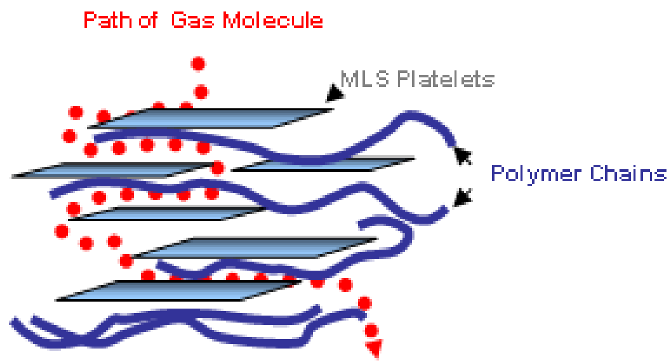

Figure 2. Tortuous Path Model

The interface between nanoparticles and polymer matrix reduces chain mobility, creating a reinforcement effect. This type of interface facilitates stress transfer to the reinforcement phase, thereby improving mechanical properties. A major advantage of nanocomposites, as compared to conventional fillers, is that only 2-8% loading is required to achieve these property improvements[5]. These decreased loading levels and the intercalated/exfoliated morphology of the nanoparticles result in no increase in film thickness and no detriment to processability. A key factor in determining the ultimate improvement in properties is the compatibility of the polymer/nanoparticle and the dispersion of the nanoparticles within the polymer matrix.

Innovative research with NSRDEC and their collaborators has led to optimized nanocomposite formulations for the MRE Meal Bag, non-retort, and retort pouches. Figure 3 illustrates the current structure of the Meal Bag and the pouches.

Figure 3. Current Packaging Structure of the MRE

The KURARISTER technology began in the late 1990s and today is being commercially produced with Food and Drug Administration approval for food contact. Expected applications in DoD are for food packaging for military rations, but this technology can also apply to consumer food packaging applications. In addition, other DoD potential applications could include the bag that holds the Joint Service Lightweight Integrated Suit Technology (JSLIST). This is the currently fielded ground crew chemical protective garment and the JSLIST suit bag is made of a multi-layer nylon/foil film. Another potential Army application is for tents and portable shelters.

Specifically, the materials in Table 1, the structures in Table 2 for the non-retort pouch and structures for the retort pouch in Table 3 are shown.

Table 1. MRE Non-Retort and Retort Pouch Materials

MF225	Rohm and Haas Mor Free 225 +C33 solventless retort grade adhesive
HDPE	Pliant 4 mil blown HDPE sealant film
CPP	Pliant 4 mil cast PP sealant film
EF-XL$_{15}$	EVAL 15 micron bi-axially oriented 32 mol% EVOH film
K-C	KURARISTER^{TM} C
K-N	KURARISTER^{TM} N
GL	Toppan GL-ARH (inorganic barrier coated PET)

Table 2. MRE Non-Retort Pouch Structure

HDPE
MF225
EF-XL$_{15}$
MF225
K-C

Table 3. MRE Retort Pouch Structure

CPP
MF225
K-N
MF225
GL

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The overall advantage of this nanotechnology packaging is that the amount of solid waste for the military would be significantly reduced. All polymeric, recyclable Meal Bags and food pouches are being produced to eliminate foil ration packaging from the waste stream. The pouches are being produced as multilayered polymeric structures with recyclable polymers and compatible nanoparticles in low percentages.

For the Meal Bag, the advantage of the new structure is that it is thinner than the existing Meal Bag, therefore less polymer resin is needed to fabricate it. The nanocomposite Meal Bag has better water vapor and oxygen barrier performance, as well as improved mechanical and thermal properties. The advantages of the current Meal Bag are that it has been used for over 20 years and has performed well for the U.S. Army; however, it may be over-engineered. The new technology may allow some commercial items in the MRE to not require overwrapping with a foil-based food pouch since it contains some barrier enhancement.

Other advantages of the new technology for the non-retort and retort pouches are the following: simplified processing with fewer steps, lower production costs, and an all-polymeric structure. No limitations have been identified. The processing methods are the same as the current pouches, but in this case the foil lamination step would be eliminated, therefore potentially decreasing manufacturing costs. One advantage of the new technology for the non-retort and retort pouches is that the barrier is maintained without the foil, therefore eliminating the pin holes and stress cracking that can occur with the current foil-based packaging. Another significant advantage to the new technology is that the nanocomposite food pouches could be microwaved or could withstand novel sterilization processes such as high pressure sterilization and Microwave Assisted Thermal Sterilization (MATS), methods which are currently being investigated as future sterilization methods for U.S. Army.

3.0 PERFORMANCE OBJECTIVES

Table 4 provides a summary of the performance objectives used for the individual ration packaging components during this demonstration and validation. The metrics, data requirements and success criteria are described in the table. The last column gives the results of the specific performance criteria.

Table 4. Performance Objective – Meal Bag, Non-Retort, Retort Pouch

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Assure recyclability of pouch	Melt temperature of polymer (°C)	Obtain melt points and reprocess the pouch	Pouch has melt temperature of 200 °C ± 20 °C	**NOT MET**
Maintain low oxygen concentration	Oxygen concentration (%)	Oxygen concentration as percentage within pouch	>90% of non-retort-pouches with <0.3% oxygen	**MET**
Maintain resistance to insect infestation	Percentage of penetrations per 30 MREs	Inspection of the pouch after insect exposure	<20% penetration failure	**MET**
Assure food is not rancid	Hexanal quantity generated in sample (ppm)	Head space analysis for hexanal quantity	<5 ppm of hexanal in all pouches	**MET**
Maintain integrity of pouch	Percentage of pouches that meet military specification for burst strength	Internal pressure testing	>90% of the pouches exhibit no rupture or seal separation > 1/16 of an inch	**MET**
Assure integrity of pouch after environmental rough handling	Percentage of defects (leaks in the pouches)	Inspection of the pouch after rough handling	<15% failure rate	**MET**
Maintain low oxygen concentration for shelf life requirements -	Concentration of oxygen (cc)	Oxygen concentration within pouch	>90% at 20 cc or less for retort pouch	**MET**
Maintain resistance to insect infestation	Percentage of penetrations per 30 MREs	Inspection of the pouch after insect exposure	<20% failure	**MET**
Assure shelf stability and microbial validation for retort	Number of colonies per gram (cfu/gram)	Aerobic plate counts (yeast and mold colonies) present on food product	<10 cfu/gram	**MET**
Maintain shelf life (water activity)	Ratio of vapor pressure of water above a sample divided by pure distilled water	Water activity analysis of food product	Water activity is between 0.10-0.50	**MET**
Qualitative Performance Objectives				
Assure recyclability with industry	Ability of industry to recycle	Response and trials from the recycling companies	Industry accepts pouch (flake) for recycling	**NOT MET**

3.1 OVERALL MRE SYSTEM PERFORMANCE OBJECTIVES

Table 5 takes the MRE packaging as a system and describes the performance objectives along with the metrics, data requirements, and success criteria. All success criteria were met.

Table 5: Overall Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Soldier acceptance of food and packaging	Scaled scores from questionnaire	Scores on survey from individual soldiers	Average score >5.0 on hedonic scale	**MET**
Reduce amount of solid waste requiring disposal	Tons/day of solid, non-hazardous ration related waste sent to landfill	Disposal data for solid waste	>30% overall weight reduction with 20% from tons/day disposed	**MET**
Assure MRE can withstand air drop transportation	Percentage of failures from packaging seals and bursts	Percentage of defects on dropped MREs	<12% failure rate	**MET**
Assure MRE can withstand distribution/ transportation	Percentage of packaging defects	Inspection of MREs after distribution and transport cycle	<20% failure rate	**MET**
Acceptance of food from sensory panel	Number (whole integer) for rating the food	Panel evaluation for flavor, taste, odor, and texture	>5.0 on hedonic scale >90% acceptance	**MET**
Qualitative Performance Objectives				
Ease of processing, filling, and packing the nanocomposite ration packaging	Observations during the processing, packing, and filling	Feedback and inspection from the converter on the filling and packing of the MREs	Pass end item inspection at co-packers with certificate of conformance and production report	**MET**

4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

The following section describes the sites where the demonstration and validation program took place. Each are described in detail.

4.1.1 NSRDEC

NSRDEC is located in Natick, Massachusetts. Most of the testing took place in the engineering and development buildings where the pertinent apparatus for the demonstration were located. NSRDEC has state of the art calibrated equipment and clean laboratories for the demonstration. There are environmental chambers for the storage study that are controlled and monitored and undergo internal safety inspections on a quarterly basis. NSRDEC laboratories performed many of the microbiological and analytical methods to ensure the food safety and to evaluate pouches and meal bag for potential recyclability. In addition, the MRE was evaluated for vibration and drop tests in the packaging laboratory at NSRDEC. All laboratories comply with safety procedures and regulations.

4.1.2 Insect Testing

Insect Testing was conducted by Moses BioLogic (MBL) at a 3500 sq. ft. warehouse facility in South Carolina. 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. Mr. Mullen is also a consultant to MBL. Environmentally controlled, walk-in testing chambers provide an excellent testing arena that controls physical factors such as temperature, humidity, and light, which can affect experimental data.

4.1.3 Assembler

AmeriQual was the facility selected for filling and packing the MREs for this demonstration. AmeriQual Group was chosen of the three MRE contractors due to past collaboration with them: the NSRDEC principal investigator (PI) worked them in the past on the SERDP 1479 project. AmeriQual filled and packed the non-retort and retort pouches with pretzels and penne pasta, respectively. This group has a quality control group that worked closely with NSRDEC to execute this portion of the project. The Veterinary Board (VETCOM) is located at the facility that handled their conformances. AmeriQual is responsive and knowledgeable of this type of demonstration plan. The Quality Assurance Manager has been involved in the project and is familiar with all criteria for failures.

4.1.4 Field Test

Fort McCoy is an active United States Army installation. It is located on 60,000 acres (240 km^2) between Sparta and Tomah, Wisconsin, in Monroe County. Since its creation in 1909, the post has been used primarily as a military training center. Today, Fort McCoy serves as a Total Force Training Center. Around 100,000 members of the military are trained at the fort every year, and the total number has exceeded 149,000 in the past[6]. Fort McCoy supports the infrastructure to execute a field study. The location was chosen based on the availability.

4.1.5 Transportation/Distribution

Several bases were selected for the transportation/distribution study due to the wide range of environmental conditions that must be assessed for this study. Fort Bliss is a United States Army base located in New Mexico and Texas. With an area of approximately 1,700 sq. mi (4,400 km^2), it is the second largest installation in the Army. The pallets were exposed to extreme heat and humidity conditions at Fort Bliss, and then shipped to Fort McCoy. Other pallets experienced the transportation route of high altitude and extreme cold conditions of Fort Richardson.

4.1.6 Air Drop

Testing was conducted at Yuma Proving Ground (YPG) for high altitude drops, Rhode Island Aviation Facility at Quonset for low altitude drops, and NSRDEC for hypobaric testing. Three major ranges (Kofa, Laguna, and Cibola) are located on the YPG facility, which allows for a unique set of testing environments. The Cibola range was the primary range used for airdrop testing due to its extensive test range equipped with video, electronic, and optical tracking systems as well as a cargo preparation complex. YPG is the Army's only facility for certifying airdrop cargo and ammunition loads. The combination of a new state-of-the-art Air Cargo Preparation Complex, essentially unrestricted airspace, and highly skilled engineers, technicians, and military riggers provides the most complete infrastructure within the DoD specifically geared toward the support of air delivery missions.

4.2 PRESENT OPERATIONS

Present operations for MRE packaging consist of a polyolefin meal bag and a multilayered polymeric pouch with foil as a barrier for the food pouches. These are purchased by one of the three assemblers and then utilized in producing and packaging of the rations. The rations follow the military specification for performance requirements.

4.3 SITE-RELATED PERMITS AND REGULATIONS

All NSRDEC laboratories are inspected quarterly to ensure compliance with the safety procedures and policies governed by the United Stated Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA). For MBL, no special permits are required for this type of experiment. NSRDEC was not aware of any permits or potential regulations needed for the field study and the transportation/distribution study. All safety regulations at the Army bases were adhered to by NSRDEC YPG required permits for recorders and cameras and all the appropriate forms were filed with YPG.

5.0 TEST DESIGN

5.1 ASSURANCE OF FOOD SAFETY

Food safety is the most important function of the food packaging. This new food packaging needs to undergo the same validation and safety tests that the current food packaging undergoes. This section describes the tests performed on the control and novel nanocomposite packaging to assure food safety.

5.1.1 Microbial Validation

Ten samples for microbiological testing were randomly selected from containers/pouches previously subjected to incubation testing. These samples were tested individually for aerobic plate counts for 48 h at 35 ºC and yeast and molds counts for 5 days at 25 ºC.

5.1.2 Water Content/Water Activity

Calibration of the balances used in the weighing of the pouches as well as for the water content and water activity was in the inspection and calibration program at NSRDEC. The company is contracted to check each balance on a yearly basis. The calibration procedure for balances was to use a known weight sample to determine the precision of the balance. The metric was the quantity of water contained in the food samples expressed as a percentage, where 0% was a dry sample. Moisture weight loss of food products is determined by drying the food in a vacuum oven and then reweighing. Water content of 3-5% was the success criteria. Water activity is a unitless value and the success criteria needed to be between 0.1-0.5.

5.1.3 Lipid Oxidation

The aldehyde, hexanal, was monitored throughout the duration of the storage study to measure the level of lipid oxidation that occurred in the penne and pretzel samples. Hexanal is a secondary lipid oxidation compound that can be used to measure the overall quality of the food, as well as the occurrence of lipid oxidation. A hexanal standard was purchased from Sigma Aldrich and run with each storage pull sequence. The sensory threshold for hexanal is 1-5 ppm, and a 1 ppm standard was run with each pull. The hexanal was extracted from the samples with solid phase microextraction (SPME) and measured with an Agilent 6890/5975 Gas Chromatograph/Mass Spectroscopy (GC/MS).

5.1.4 Burst Test

Internal pressure testing using a Lippke 2500 SL was performed for eight samples at each storage pull temperature and time. The success criteria was met as 100% of the non-retort pouches exhibited no rupture or seal separation greater than 1/16 of an inch.

5.1.5 Oxygen Concentration

The sample size for oxygen was eight pouches for each test. The military specifications dictated the sample size, but it was not based on the American National Standards Institute (ANSI) tables like the other end item exams. Data analysis was based on the Military Performance (MIL-PRF)-44073F performance specification. Therefore, if one sample deviated from the specification result required for the test, then there was a failure of the entire lot.

The level of oxygen in the package was assessed after the pouches were removed from the storage study and had undergone exposure to different environments. Standard statistical methods were employed with the data collection. Mean average values were reported using eight samples per pull.

5.1.6 Acceptance of Food from Sensory Panel

Samples were prepared and stored for various time intervals and at various temperatures. Testing was done in real time over the period of 36 months. Accelerated shelf life measures (100 °F and 120 °F) were completed in 6 months and 4 weeks respectively.

Two types of sensory panels were conducted: (a) Technical panels and (b) Consumer panels. The trained panelists evaluating the products for quality in five domains: (1) Appearance, (2) Flavor, (3) Odor, (4) Texture, and (5) Overall. The trained panels (referred to as “tech panels”) use a 1-9 point sliding scale. Lowest quality ratings are a ‘1’ and highest quality ratings are a ‘9’ along a continuum. Trained panelists generally rate acceptable quality at a 7 on most products.

Analyses were performed using Sensory Quality Panel Software Systems (SIMS) 2000, MS Excel and the statistical analysis tools. Analysis of Variance (ANOVA) and means comparisons were performed. For the statistics, standard statistics (mean, Standard Deviation [SD], min, max, standard error, and variance) and NSRDEC performed a few post hoc tests such as a comparison of the means with either a Duncan's or Tukey's Honest Significant Difference (HSD or both).

5.1.7 High Velocity

Unitized loads were delivered from a C-130H aircraft via conventional parachute systems for high velocity delivery bundles, delivering from an altitude of 1,500 ft. The high velocity unit load configuration is shown in Figure 4.

The unit loads tested consisted of 48 cases assembled in accordance with normal assembly procedures. The samples were configured in a 3 x 4 pallet pattern with a column stack of four containers. Each load utilized a standard wooden pallet with additional honeycomb material positioned underneath the pallet for product protection during impact.

Figure 4. High Velocity Unit Load Configuration (Five Layers of Honeycomb)

5.1.8 Delivery

The aerial deliveries of the MRE rations were characterized with the internal data recorders, which helped identify and define four unique stages of the delivery process to include: 1) deployment, 2) parachute opening, 3) descent, and 4) impact. The four stages, shown in Figure 5, represent significant levels of velocity change as each load exits the aircraft and descends to the landing zone. The deployment phase begins when the rear cargo door and ramp of the aircraft are opened just prior to release of the unit loads. Once the aircraft has identified the proper drop altitude, the aircraft pitches slightly and the loads fall out of the back of the aircraft from their own weight. Once the unit loads exit the aircraft, they enter into an initial free fall lasting a few seconds where the parachute is still bundled. The parachute then opens, and descends to the ground, where it makes impact.

Figure 5. Drop Sequence for Aerial Delivery

Page Intentionally Left Blank

6.0 PERFORMANCE ASSESSMENT

Figure 6 shows all the pallets of MREs that were generated for the demonstration and validation plan.

Figure 6. Pallets of MREs for ESTCP Program

6.1.1 Microbial Validation

Microbiological tests were conducted throughout the storage study, at predetermined intervals, to determine the number of colonies of microorganism per g, which was the metric for this objective. The data requirement was a test analyzing the aerobic plate count for yeast and mold colonies present in the retort pouch food product. The success criterion was met as there were fewer than ten colonies per g in the food sample for samples tested. The control and nanocomposite packaging behaved the same.

6.1.2 Water Content/Water Activity

The control water activity was approximately .200 at 2, 4 and 6 months while the nanocomposite pouch decreased from .18 to .16 to .15 at 2, 4, and 6 months, respectively. The water content for both the control and nanocomposite pouches ranged from 4.4% at 2 months to 3.5% at 6 months with no significant differences when the error bar was considered.

The results were all consistent for the controls for water activity with values in the .2 to .25 range. The nanocomposite pouch began with a higher water activity of .33 and increased to .44 to .53 by 36 months.

6.1.3 Lipid Oxidation

All samples measured a hexanal abundance level less than 1ppm (documented threshold for sensory recognition).

The aldehyde, hexanal, was monitored throughout the duration of the storage study to measure the level of lipid oxidation that occurred in the penne samples just as was done for the pretzel samples.

Hexanal abundance was below the sensory threshold and there was almost no difference between the different control and nanocomposite samples.

6.1.4 Sensory Analyses

Most notable results demonstrate a large negative impact of “Non-retort Nano” treatment on pretzels stored for 30 months at 40 °F and at other time/temperature combinations. The texture of these pretzels was noted for being stale and soft/non-crunchy (the normal attribute is ‘crunchy’ for this product). There were less notable but still significant differences in some of the other comparisons.

6.1.4.1 Non-retort Nano vs. Non-retort MRE

It appears that pretzels stored at cooler temperatures are more negatively impacted by the use of ‘Non-retort Nano’ packaging.

6.1.4.2 Retort GL/K-N Nano vs. Retort MRE

Figure 7 displays the sensory data at 36 months for the non-retort pouches (control and nanocomposite). This data reveals that the appearance, odor, and flavor scores are similar for the control and nanocomposite packaging, but for texture and overall quality, the nanocomposite structure has unacceptable values; this is due to the water barrier not being as high as the control pouch. The pretzels lose some of their crunch at approximately 30 months. Figure 8 displays the sensory data at 36 months for the retort pouches (control and nanocomposite). This data shows that the nanocomposite pouches stored at 80°C did not obtain as high of a score as the controls, but the values still pass the success criteria. The nanocomposite pouches stored at 40°C received comparable scores from the sensory panel in all categories.

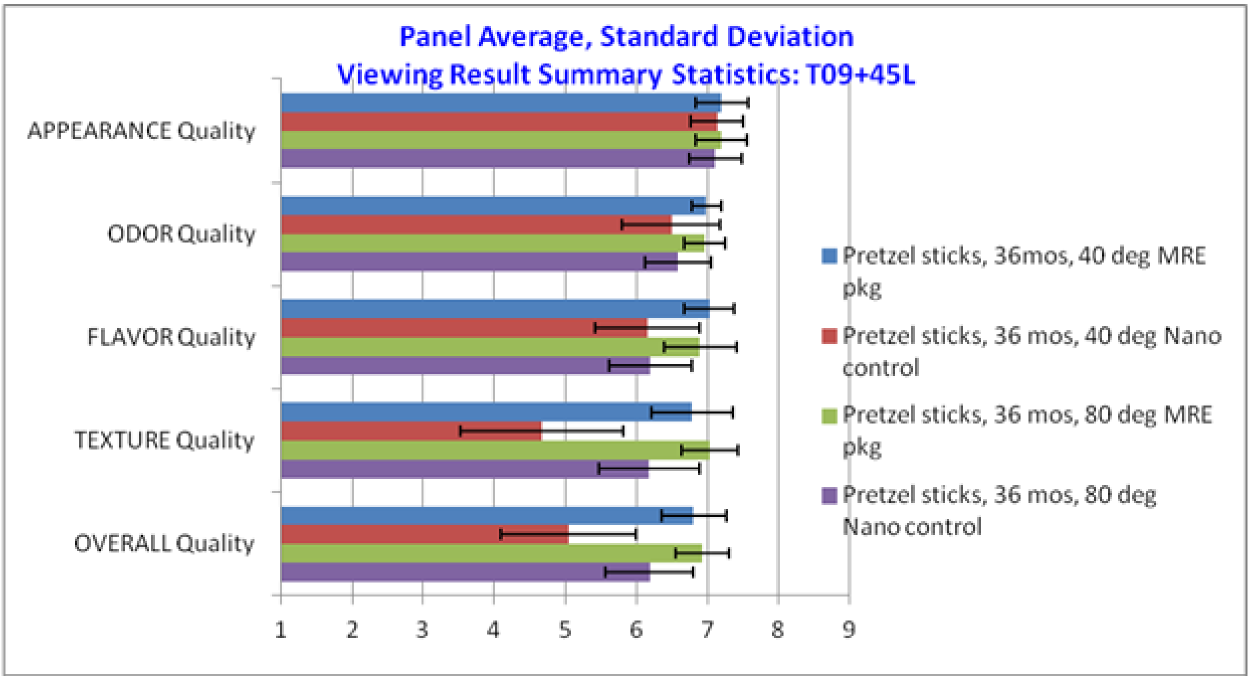

Figure 7. Sensory Studies of Pretzels in Non-retort Pouch at 36 Months. (MRE Package and Nano Pouch)

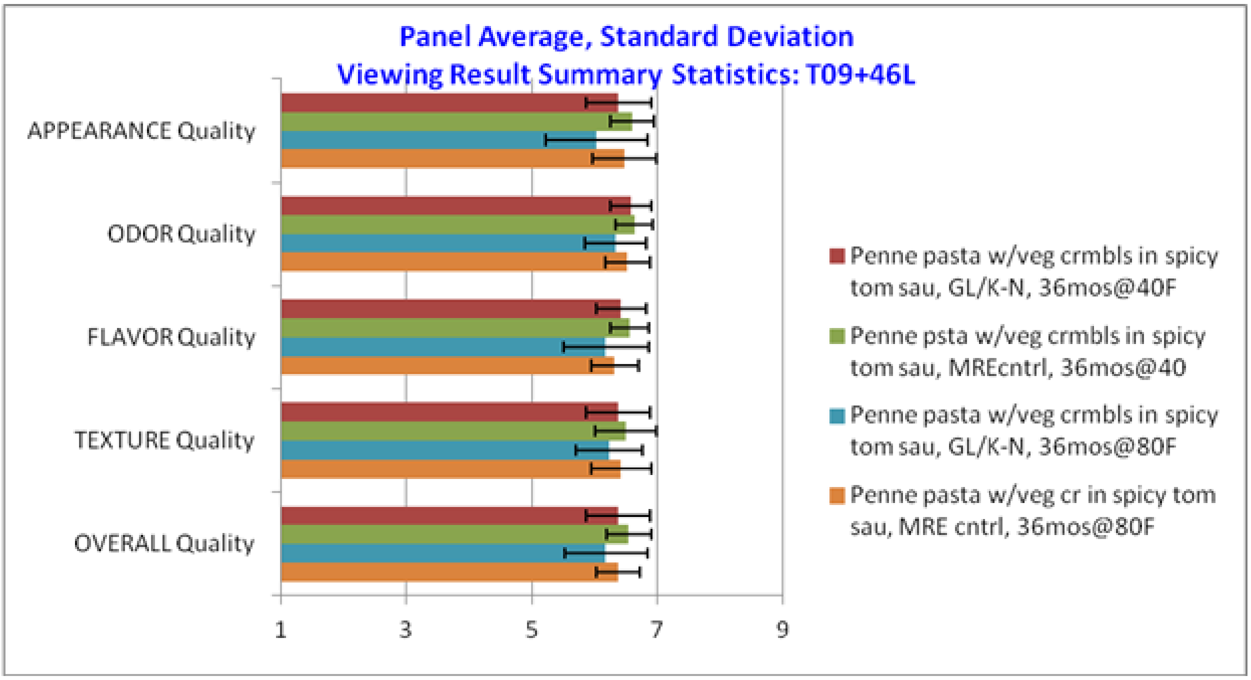

Figure 8. Sensory Studies of Penne Pasta in Retort Pouch at 36 Months. (MRE Control and Nanocomposite) (GL-KN)

6.1.5 Assurance of Recyclability of Meal Bag

The control Meal Bag had a melt temperature of 126.5 °C ± .20 and the nanocomposite Meal Bag was 118.9 °C ± .15, which lies in the range for success criteria. All the formulations ranging from MRE Meal Bag regrind from 0-100% that were evaluated for recycling.

MRE control Meal Bags and the nanocomposite Meal Bags were able to be processed at all percent weight compositions. The films processed better at the higher compositions of pure virgin Low-Density Polyethylene (LDPE) rather than the regrind. Regrind material has already been processed and this may have caused some lowering of the molecular weight which can diminish mechanical properties.

Quantitative Statement.

Based on these findings, both the control Meal Bag and the nanocomposite Meal Bag would be suitable for TREX recycled PE stream at 25% inclusion rates based on polymer rheology. The amount of pigment and color loading would limit the inclusion to certain TREX products based on color specs. There does not appear to be a significant processing advantage to either the control sample or the nanocomposite sample.

TREX analyzed the non-retort and retort pouches and determined that they could not be recycled with the type of machinery due to the mix of plastics. TREX has one of the most state-of-the art machines for recycling; therefore, if the pouches could not be recycled at their facility, the chances of recycling at another facility were not likely. Alternatives to recycling for this lightweight polymeric packaging, could be the waste to energy converters.

6.1.6 Insect Infestation

All pouches were inspected for chew damage by submerging the pouch under water and checking for air leaks. There were no failures. A criterion for success was that there was less than 20% penetration failure in comparison to the current MRE retort pouch.

6.1.7 Integrity of Meal Bag from Rough Handling

This testing was conducted to determine compliance with the military specifications regarding performance. Figure 9 shows drop tester equipment that was used for this evaluation.

The success rate was less than 15% failure, which was met. The entire pallet was rough handled and the inspections were then conducted on the non-retort pouches, the Meal Bag, and the retort food pouches.

Figure 9. Drop Tester

6.1.8 Retort Pouch

Three failures out of 576 were found in the retort pouch:

- Seal failures due to food entrapment were found in various cases.
- No seal failures were found on the prototype retort material.
- Stress whitening was often found throughout the retort pouch and was concentrated in areas where the carton had been compressed. Some stress whitening was found at the tear notch of the retort pouch.

The nanocomposite retort pouch showed signs of stress whitening of the pouch and was common for items that were handled roughly during testing.

Table 6. Defect Summary of Samples

		Layer 1	Layer 2	Layer 3	Layer 4	Total	%Avg.
Control	**Meal Bag**	9	6	4	10	29	5.5
	Retort	2	0	0	1	3	0.6
	Non-Retort	12	14	14	11	51	9.7
Nano	**Meal Bag**	6	12	15	6	39	7.4
	Retort	1	0	0	0	1	0.2
	Non-Retort	0	0	1	1	2	0.4

An inspection summary of the rough handling is found in Table 6. The inspection of the samples were done for each case of MREs. The position of a case on a pallet can influence the defects. Layer 1 represents the cases on the top of the pallet, while Layer 4 are the cases on the bottom of the pallet.

Overall, the nanocomposite retort and non-retort defects were less than the control pouches. The nanocomposite Meal Bag had a slightly higher number of defects, but all met the success criteria.

6.1.9 Field Test Results

The Soldiers completed questionnaires at each meal for the MRE they were issued over the course of the evaluation. The analyses of these data are presented below.

Acceptability (liking) of the penne pasta and the pretzels was rated on a 9-point scale. The soldiers rated how much they liked the spicy penne pasta and the pretzels under each of the three packaging conditions. A one-way-analysis was performed on these data. There were no statistically significant differences in how acceptable (likable) the penne or the pretzels were under the three different conditions, as can be seen in Table 7.

Table 7. Field Study Question: Acceptability (Liking)

Penne Pasta Retort Pouch	**Control**	**GL/KN Nano Retort**
	718	728
Mean	6.08	6.25
Std. Deviation	1.832	1.833
N	95	100
Pretzels Non-retort Pouch	**Control**	**Nano non-retort**
	718	728
Mean	6.92	6.66
Std. Deviation	1.651	1.688
N	90	94

No significant differences (one-way $p > 0.05$).

Based on the data collected during this field evaluation, it may be concluded that both versions of the test packaging are at least as good as the control packaging in terms of the flavor of the packaged food, ease of opening the packaging, and satisfaction with the temperature of the heated retort item.

6.1.10 Reduction of Solid Waste

The objective was to reduce the amount of solid waste requiring disposal, which has substantial relevance to the demonstration for the overall goal to reduce solid waste.

Size and weight comparisons of the packaging components are shown in Figure 10. A characterization study generating the amount (weight) of the disposed solid waste is necessary. It would be considered a success if there was a greater than 30% reduction in the solid waste with 10% being able to be recycled.

Meal Bag		Retort Pouch		Non-Retort Pouch	
Control	Nanocomposite	Control	Nanocomposite	Control	Nanocomposite
					
Thickness (mil)					
10.92	7.05	5.12	5.50	4.02	5.80
Size (mm)					
350 x 221	350 x 221	204 x 118	204 x 118	210 x 126	210 x 126
Weight (g)					
39.92	25.43	6.90	6.42	5.68	7.75
Percent Weight Reduction (%)					
-	36.3	-	7.0	-	-36.3

Figure 10. Size and Weight Comparisons of the MRE Packaging Components to Include the Meal Bag, Retort Pouch, and Non-Retort Pouch

Packaging weight calculations were estimated by obtaining the average weight of a known area (circle cutout with a radius of 12.7 mm) and integrating it with the actual size of a standard pouch to obtain a comparative weight analysis of the control packaging and nanocomposite packaging items. The following calculations were used to obtain the estimated total weight of each package: $W_p = (W_c / A_c) \times (A_p \times 2)$; where W_p is the estimated total weight of a pouch, W_c is the weight of the circle cutout, A_c is the area of the circle cutout (506.71 mm^2), A_p is the area of the standard pouch size calculated by multiplying the length and width of each pouch and a constant (2) to account for the total material used to construct the two sides of each pouch.

Once the estimated total weights were obtained, the percent reduction was calculated for each of the Meal Bag, retort pouch, and non-retort pouch items. The weight reduction estimates per pouch were also used to calculate the weight.

6.1.11 Cross Country Shipment and Cold Weather Storage – Fort Richardson

The results shown are based on visual inspections of the MRE test samples that included existing control systems, nanocomposite Meal Bags, retort pouches, and non-retort pouches. From each sample lot, seven cases of each material type were inspected with four rations from each case inspected by VETCOM and the remaining eight rations from each case inspected by NSRDEC engineers. The focus was on examining the food quality and packaging integrity of the prototype and control systems. The VETCOM inspectors examined the food quality to include overall taste, odor, and appearance. In addition to examining the food items, VETCOM inspectors also examined the existing packaging controls as well as the prototype nanocomposite packaging. NSRDEC engineers focused on examining solely the packaging elements of the combat rations with a focus on identifying critical failures in the packaging that may reduce shelf life of the MRE components or inadequately protect the ration items.

The Meal Bags that were inspected for this study showed eight types of failure or damage to the packaging that may reduce the overall effectiveness of the package and system as a whole in protecting the ration items. In addition to the eight types of failures, some Meal Bags were categorized as having no visible damage to the package. Upon visual inspection these test samples were found to have no major signs of failure such as a burst seal or torn/punctured film that would expose the internal components to the external environment. One type of failure was stress marks or punctures from the corner of the carton from the main entrée. When packed on the outside of the carton, there may often be punctures or stressing of the Meal Bag due to over-packing of the internal components and limited space within the secondary shipping container.

The assessment of the nanocomposite non-retort pouches filled with pretzels revealed no significant damage to the pouch structure. Destructive open package inspection was performed on 18 of the 144 cases in which six cases were randomly inspected from each of the three test pallets. The destructive package inspections revealed defects in only the nanocomposite retort pouches, yielding a failure rate of 5.6% of the samples inspected. The examination of the penne pasta nanocomposite retort pouch showed that the test samples had only slightly higher failure rates at the manufactured seal area in comparison to the existing retort pouches and yielded a failure rate below 15%, which was the set limit under the project goals.

7.0 COST ASSESSMENT

This chapter provides sufficient cost information for implementing nanocomposite polymeric packaging and its life-cycle costs as compared to the currently fielded foil laminated food pouches. In addition, discussion of the cost benefit of the technology is presented.

7.1 COST MODEL

This section discusses the methodology used in the cost assessment, which is based on material weight and cost. The cost of the polymer can fluctuate with market prices, but the nanoparticle additives have more stable pricing. Polymeric structures with nanoparticles for food pouches for ration packaging can take the form of multiple layers with varying thicknesses. The price per pouch decreases as the number of polymeric layers in the film decrease as shown in Table 8.

Table 8. Cost Variation as a Function of Number of Polymer Layers

Width, inches	70	60	50	40	35	30
Length, yards	250	292	350	438	500	583
MSI*	630	630.72	630	630.72	630	629.64
2-ply	$ 375.55	$ 375.98	$ 375.55	$ 375.98	$ 375.55	$ 375.33
3-ply	$ 427.82	$ 428.31	$ 427.82	$ 428.31	$ 427.82	$ 427.58
4-ply	$ 486.41	$ 486.97	$ 486.41	$ 486.97	$ 486.41	$ 486.13
Cost Savings 3-ply over 4-ply	12%	12%	12%	12%	12%	12%
Cost Savings 2-ply over 4-ply	23%	23%	23%	23%	23%	23%
2 rolls each	$2,579.56	$ 2,582.50	$ 2,579.56	$ 2,582.50	$ 2,579.56	$ 2,578.08

*Thousand Square Inches (MSI)

Activity-based costing methodology for each element is listed. The cost elements associated with replacing the existing technology with the alternative technology are listed and discussed. The assembler that buys the current Meal Bag and pouches, AmeriQual Packaging, was consulted for prices of current items. A Meal Bag producer, Blackbird, and a resin provider, Kuraray America, were also consulted for prices, cost elements, and a cost/benefit analysis.

Assumptions factored into cost/benefit calculations include less environmental burden for the Meal Bag since they can be recycled, they are thinner and therefore use less material, and there are potential reduced costs associated with a co-extruded pouch versus a foil laminated pouch.

7.1.1 Processing and Pouch Formation Costs

The first cost element is for the processing of the nanocomposite films and the trials to form the film into the Meal Bag and food pouches. The cost estimate was based on the cost of the labor and machine time. The data was presented as a cost per Meal Bag in comparison to the current components. The manufacturing costs of the new technology are the most important costs for the life cycle analysis. The new technology does not laminate with aluminum foil, but laminates polymers together for the non-retort and retort pouches.

7.1.2 Resin (Polymer) For Manufacturing

This element addresses the amount of resin that is needed for the production of the Meal Bags and the food pouches. Resin amounts were less than the existing technology, especially for the Meal Bag. Also, the cost of using nanoparticles in the Meal Bags, and the barrier coated materials for replacement of the foil in the retort and non-retort pouches are addressed in this element. Market resin prices at time of test were used to determine cost.

7.1.3 Filling/Sealing Process of Food Pouches

This element addresses how the line speed was affected by using these new packaging materials. Labor and time for filling and sealing need to be recorded as this could influence the processing costs. Material scrap should also be accounted for during the fill and seal to compare to existing technology.

7.1.4 Disposal Costs

This element determines the amount of waste to be disposed of and the costs associated with that. This was based on the waste characterization. This data was scaled up depending on the procurement of MREs and it was also compared to the existing MRE packaging. Cost savings due to recycling of bags was also addressed here.

7.1.5 Shipping and Handling Costs

This element addresses the shipping and handling costs. Data was obtained on all the costs incurred for shipping the pallets of MREs throughout the demonstration. The costs were compared to those for existing MREs. The nanocomposite packaging could potentially cost less to ship due to the lighter packaging.

7.1.6 Soldier Training

The element of soldier training is needed to educate the soldier on the new packaging and possible disposal options (if recyclable). This is important but perhaps somewhat invisible since the new packaging may not appear significantly different than the current packaging. This has life cycle costs associated with it for all soldiers would need to be informed on the sorting of this new packaging for disposal.

7.2 COST ANALYSIS AND COMPARISON

This section provides realistic estimates for the costs of the alternative technology when implemented operationally.

Initiatives focused on materials research and packaging optimization through down gauging, material selection, and packaging design have demonstrated that MRE waste reduction efforts can yield substantial savings in direct material cost and additional reductions in overall life cycle sustainment costs. Transitioning new material solutions and packaging designs can create annual savings of approximately $5 million (use Estimated Weight Savings over 1 year) – 452,936 by reducing packaging in the following ways: reducing thickness of the Meal Bag, optimizing polymeric structures to better meet military stringent performance requirements, and eliminating redundant or excess packaging for individual combat rations.

By reducing the thickness of the meal bag from 11 mil to 7 mil, the DoD would be able to reduce packaging requirements by 36.3%, equivalent to approximately 450,000 lb. or 226 tons of packaging material over one procurement cycle of 1 year. In the first 3 years of integration, the DoD can potentially save an estimated $2.8 million (use the weight savings of 1,358,809 lb. over 3 years, multiply by $/lb. of control packaging, and then subtract the cost of the nanocomposite material again using the 1,358,809 multiplied by the $/lb. of the nanocomposite material for total packaging material costs).

The optimization of the MRE Meal Bag and component packaging is considered a high payoff effort that would have a tremendous impact on the subsistence supply chain. The reduction in packaging would impact operations across the supply chain, including critical activities such as raw materials sourcing, packaging procurement, manufacturing, ration assembly, and distribution activities. Logistics operations would also be impacted by the reduction in packaging materials with transformations seen in transport, storage, and disposal operations. Sourcing of the raw material and packaging components would be the activity most affected by the change in packaging material. The developmental efforts described in this report have created a Meal Bag that has reduced thickness and overall weight when compared to the AmeriQual Meal Bag. The AmeriQual Meal Bag has a thickness of approximately 11 mils, while the nanocomposite Meal Bag has a reduced thickness of 7 mils. This difference in polymer film thickness results in a weight difference, and is estimated to eliminate 91 shipments from the ration assemblers to storage depots and provide additional savings as they are redistributed throughout the U.S. and abroad. Additionally, large scale savings in material usage would also result from this effort. For example, the amount of polymeric case banding material used to seal MRE containers would be reduced by 6 inches per container, creating an annual savings of 1.1M linear ft. of polymeric banding material. The weight reduction from this change would add up to approximately 321,000 lb. per procurement cycle. Design changes proposed for the Meal Bag alone would create an estimated 0.046 lb. reduction in packaging film per meal, and based on an average procurement of 40M rations this change would eliminate approximately 1.2M lb. of plastic packaging from the waste stream. The PlasticsExchange.com website recently estimated linear low density polyethylene film at $0.8/lb., is projected to gradually increase as unrefined petroleum prices continue to escalate. At this commodity price, an estimated savings of $1.3M can be realized in the first year of implementation with the proposed reduction in material. In addition to logistics improvements, the individual Warfighter would also benefit from a reduction in overall weight and size, as a more compact ration would be easier to pack and carry and would reduce unnecessary packaging waste generated in the field. The reduction in waste would also result in fuel, time, and cost savings associated with backhauling waste and disposing of discarded packaging material. This reduction in waste would create an environmental advantage as well.

The AmeriQual data for existing pouches is as follows:

- Retort 8 oz. preformed LINEAL TEAR $.0838
- Non retort - SNACK POUCH $.037

Kuraray reported that the pricing for the nanocomposite retort pouches is: $0.047-059 per pouch.

The calculations for the Meal Bags utilizing the current material and the nanocomposite material are as follows:

- Bag Length x Width x Thickness (gauge in mils) divided by 15 divided by 1000 bags per case was equal net lb. per case.
- For a MRE bag, 15 in x 8.5 in x 11 mil equals 1402.5 divided by 15 equals 93.5 divided by 1000 equals .0935 x 11 equals about 1 lb.
- There are approximately 11 bags per 1 lb. for the control Meal Bag.
- For the MRE nanocomposite meal bag performing the same calculation with a 7 mil bag, there would be about 16 Meal Bags per about 1 lb. However, the cost of the nanoparticles must be added to the cost.

The entire cost element can be used to estimate the life-cycle costs for implementing and operating the demonstrated nanotechnology. The following were considered: (1) facility capital cost which is not necessary for the nanocomposite packaging since there are already many manufacturers with the existing equipment to make the film and pouches simultaneously, (2) there may be start-up and operations and maintenance costs, (3) there are no significant equipment replacement costs for manufacturing or assembly of the rations, and (4) re-processing or re-application costs are not applicable. The timeframe for the life-cycle cost estimate would begin once the pouches are produced.

8.0 IMPLEMENTATION ISSUES

The implementation of this technology depends on the results and completion of further performance testing of other food items. The decision process requires that upon completion and assuming positive results, there would be a decision brief presented to the Joint Service Operational Rations Forum (JSORF) summarizing the technology and the significant results. This JSORF board is comprised of voting members for the services to implement new items and technology for the Warfighter. If a positive decision is made, implementation of this technology can occur.

This technology has been briefed internally at NSRDEC and to the Combat Feeding Research and Engineering Program (CFREP) Board to keep them abreast of this work.

Stakeholders include:

- Combat Rations Team of the Combat Freedom Directorate (CFD)
- Food Engineering and Science Team (FEST), CFD
- Director, CFD
- Assemblers of rations (AmeriQual, Sopacko, Wornick) who have the choice to purchase these types of pouches for the rations
- Defense Logistics Agency (DLA) Troop Command who contracts the assemblers and purchases ration items.

Recyclability of the non-retort and retort pouches were the only success criteria that were not met, and this does not have an impact on transitioning the technology, because currently, there is no recycling infrastructure for the military in combat.

Currently, there are no environmental or worker safety regulations, current or proposed, that would impact the implementation of the technology. The manufacturing would be simplified with no lamination steps, and manufacturing plants are set up to work with high barrier polymers and nanoparticles. The assembly trials in the demonstration and validation execution discussed any safety regulations that would need to be addressed.

For procurement issues, there is no special equipment required for implementation, as DLA would be procuring an award to the assembler who would then buy pouches to comply with the specifications in the contract. The ease of production and scale-up was verified in this demonstration/ validation project. The pouches can easily be manufactured on a company's existing co-extrusion equipment. The polymeric nanocomposite pouches for this demonstration were specific to a certain company providing the nanoparticles and their polymeric materials. This effort wants to expand the transition to include any polymeric high barrier structure that can meet the military requirements. In the technology transfer efforts and the ongoing work after this study, the non-retort and retort pouches have been expanded to other structures. The specifications for the military need to be modified to state the performance requirements. This all polymeric pouch can replace a foil laminated pouch and this needs to be reflected in the specifications. In addition, for this demonstration project, only one of the three assemblers, AmeriQual Packaging, participated in the study. NSRDEC has been working with other assemblers to educate them on the work and the potential pouches.

There is intellectual property for the nanocomposite structures within the suppliers of the material, but this should not affect the transition since the assemblers just buy pouches that meet a certain performance specification.

This nanocomposite polymeric packaging for the MRE can be expanded to the group rations within the Army and also be considered for other services.

Table 9 shows ongoing work currently with other food products to evaluate the nanocomposite package for non-retort and retort foods. If upon completion of a six months storage study with these materials the results are successful, this technology would be ready to implement. The Army is also investigating other sterilization methods besides retort for the future, so these food items are currently being evaluated also with the other methods.

Table 9. Products for Accelerated Storage Study

Retort/Non-retort	Product Category	Proposed Food Item
Retort	High Acid	Spicy Penne Pasta
Retort	Low Acid	Pork Sausage with Crème Sauce
Retort	Water**	Water
Non-retort	High Moisture	Filled/baked item, sandwich, cinnamon bun
Non-retort	Low Moisture	Snacks (i.e., pretzels)
Non-retort	High Fat	Peanuts, pound cake
Non-retort	Full Vacuum	Peanuts, crackers
Non-retort	With O2 Sachet	Nut raisin mix with M&M's
Non-retort	Hot Fill	Cheese and/or peanut butter spreads

**Water (retorted at 275 °F for 90 min) to test package integrity under stressful retort conditions and to simulate worst case product rough handling tests.

9.0 REFERENCES

1. Shah, A.P., Gupta, R. K., Hota V. S. and Powell, C.E. Polym. Eng. Sci., 42, 1852 (2002).

2. Pinnavaia, T.J. and Beall, G.W. "Polymer Clay Nanocomposites" John Willey & Sons Publishing, (2001).

3. Kornmann, X., Berglund, L.A., and Sterte J., Polym. Eng. Sci., 38, 1351 – 1357 (1998).

4. LeBaron, P.C., Wang, Z., Pinnavaia, T.J., "Polymer- layered Silicate Nanocomposites: An Overview", Applied Clay Science, 15, 11-29 (1999).

5. "Fort McCoy timeline." La Crosse Tribune 8 May 2005.

6. ASTM International D5276 Standard Test Method for Drop Test of Loaded Containers by Free Fall

7. ASTM International D1709-03 Standard Test Methods for Impact resistance of plastic film by the free-falling dart method

8. ASTM International D4728-06 Standard Test Method for random vibration testing of shipping containers

9. ASTM International D3418 Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

10. ACR-M-029 October 3, 2008 Section C, C-1 Item Description. "ACR-M-029, Meal, Ready-To-Eat, Assembly Requirements

11. MIL-PRF-44073F September 2, 2001 (with change 06 on 4 December 2008) Performance Specification Packaging of Food in Flexible Pouches

12. ASTM International D3985 Standard Test Method for Oxygen gas transmission rate through plastic film and sheeting using a coulometric sensor

13. ASTM International E96/E 96M-05 Standard Test Methods for water vapor transmission of materials 2005

14. ASTM International D6653-01 Standard Test Methods for determining the effects of high altitude on packaging systems by vacuum method

Page Intentionally Left Blank

APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Fax Email	Role in Project
Dr. Jo Ann Ratto	NSRDEC 10 General Greene Ave; Natick, MA 01760	508-233-5315 joann.r.ross.civ@mail.mil	Principal Investigator
Ms. Robin Altmeyer	AmeriQual Packaging	812-421-4876 altmeyer@AMERIQUAL.COM	Assembly
Mr. Rich Benney	NSRDEC	508-233-5385 richard.j.benney.civ	Air drop
Ms. Nicole Favreau	NSRDEC / CFD	508-233-4900 nicole.f.farhadi.civ@mail.mil	Lipid oxidation
Ms. Wendy Johnson	NSRDEC	wendy.k.johnson26.civ@mail.mil	Field Test
Mr. Gene Medlock	Kuraray America	713.495.7363 gene.medlock@kuraray.com	Fabrication of Pouches

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org