Project No./Center No.: E-27-610 (R6303-0A0)

Project Director: Dr. L. H. Olson

Sponsor: Naval Weapons Support Center, Crane, Indiana

Agreement No.: Purchase Order No. N00164-87-M-3524

Award Period: From 3/24/87 To 9/30/87 (Performance) 9/30/87

Sponsor Amount: New With This Change Total to Date

Contract Value: $ 24,554 (Fixed Price)

Funded: $ 24,554

Cost Sharing: $ 24,554

Cost Sharing No./Center No.: GTRC/ONR

Cost Sharing: No.

Project Director: Dr. L. H. Olson

Sponsor Technical Contact: Dorothy Devine 1163D/SM

Sponsor Issuing Office: Contracting Office

Naval Weapons Support Center

Crane, Indiana 47522-5011

Military Security Classification: Unclassified

ONR Resident Rep. is ACO: Yes

Defense Priority Rating: DO-B20

RESTRICTIONS

See Attached Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with (N/A—none proposed or authorized)

COMMENTS:

SPONSOR'S I.D. NO. 02.103.005.87,001

Sponsor Technical Contact: E. Faith Gleason

OCA Contact: E. Faith Gleason

REVISION NO. 4/28/87

DEPARTMENT OF THE NAVY

SUBJECT: Design and Analysis of Aging Properties of a Flame Retardant Carrier.

(2) Sponsor Issuing Office:

June 26, 1987

Dorothy Devine 1163D/SM

Contracting Office

Naval Weapons Support Center

Crane, Indiana 47522-5011

Military Security Classification: Unclassified

ONR Resident Rep. is ACO: Yes

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COMMENTS:

GEORGIA INSTITUTE OF TECHNOLOGY

ORIGII"L REVISION NO.

4/28/87

COMMENTS:

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COMMENTS:
GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 6/2/88

Project No. E-27-610

School/Div TF

Includes Subproject No.(s) N/A

Project Director(s) L. H. Olsen

Sponsor Naval Weapons Support Center

Title Analysis of a Flame Retardant Carrier

Effective Completion Date: 9/30/87 (Performance) 9/30/87 (Reports)

Grant/Contract Closeout Actions Remaining:

☐ None

☐ Final Invoice or Copy of Last Invoice Serving as Final Release and Assignment

☐ Final Report of Inventions and/or Subcontract: Patent and Subcontract Questionnaire sent to Project Director

☐ Govt. Property Inventory & Related Certificate

☐ Classified Material Certificate

☐ Other

Continues Project No. Continued by Project No.

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INTRODUCTION

The project effort undertook the identification of design parameters and design, construction and testing of a flame retardant carrier. The following report comments upon the sequence of fabric design from fiber selection through analysis of fabric properties. Also included are information on flame retardancy and sewing of the carrier to its final geometry. Design requirements are enumerated in the following text.

FABRIC DESIGN

A. Fiber Selection

The first element of fabric design is fiber selection. The carrier properties affected by fiber choice are: sea water resistance, chemical/solvent/stripping agent resistance, strength, abrasion resistance and stability with time of these properties. Polyester was selected as the optimum fiber for carrier use. That is because the design life was 30 years in an environment which could include long soaks in up to 125°F sea water and some contamination with oil or fuel residue. Additionally, the carrier may be loaded with about twenty pounds of spheres and then subjected to materials handling abuse. The abuse includes dropping from a 10-15 ft. height, abrasion against a rough surface and snagging against projecting objects such as bolt heads. Economy and ability to be processed also affect fiber choice.

Polyester fits these criteria as the carrier fiber. Reviewing the choices, the high temperature fibers - Teflon,
Nomex, and PBI - are weak, ranking 1/2 or less of the strength of polyester. Furthermore, these fibers and Kevlar cost 5-15 times the cost of polyester. Kevlar while a high strength, high temperature fiber, has very low abrasion and bending resistance.

Nylon is the tough, abrasion resistant competitor with polyester. The problems with nylon are that it does not have long term stability (textile mills sell nylon fiber from stock after 6-12 months of warehousing - this is due to internal changes in fiber structure), nylon is deteriorated by some dilute acids and peroxide/hypochlorite oxidizing agents. While phenol and meta cresol degrade both polyester and nylon, polyester resists attack by many common organic chemicals, acids and bases. Specifically, coal tar, glycerol, ethylene glycol (antifreeze), mineral oil, kerosene, gasoline, perchlorethylene, and Stoddard solvent do not affect polyester in long term (1000 hours) at temperatures up to 200°F.

The cause of reported weakness in a soil contaminated polyester carrier tested at NWSC, Crane has not been identified as yet, and clearly points to the value of maintaining relatively clean storage spaces. Extensive testing by DuPont in their Bulletin X-215, "Resistance of Fibers to Organic Chemicals", of their various fibers showed polyester to be excellent from this point of view of chemical resistance.

B. Fabric Construction

The carrier is intended to be packed with spheres and act in such a way as to constrain the spheres geometrically so that when many carriers are stored in a container, they will pack in a pattern of optimum efficiency. Packing efficiency is discussed in the appendix. A value of 0.785 is found in that analysis of volumetric packing.

The drape and extensibility of the fabric are important to carrier conformability. To achieve this conformability, a knit construction was selected. Knits have geometrical elasticity due
to being formed from loops. Among knit constructions, a Raschel knit offers unique pattern capabilities. A desire to have the carrier fabric release contained water rapidly after immersion led to choice of a Raschel mesh fabric with holes in the surface. Such patterns have been long known in fancy domestic laces and athletic wear. The fabric requires no unusual technology to manufacture. It does not run and has high tear resistance.

Including economy, fabric bulk and strength as design criteria the following fabric properties were obtained after investigating several fabrics:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areal density</td>
<td>0.36 lbs/yd²</td>
</tr>
<tr>
<td>Mesh Hole density</td>
<td>17 holes/in²</td>
</tr>
<tr>
<td>Ball burst strength</td>
<td>100 lbs.</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>120 lbs (along lengthwise or cross directions)</td>
</tr>
</tbody>
</table>

These values are based upon testing performed according to Federal Test Method Standard No. 191A,
Methods: 5120 - Ball burst
5041 - Weight of Textile Material
5100 - Breaking Strength of Cloth

The carried mass is approximately seventeen (17) pounds. The tensile strength assures a factor of safety exceeding four (4) to allow for impact loading and ageing.

C. Fabric Fire Retardancy

The vertical flame test used is Fed. Std. 191A, Method 5903-Flame Resistance of Cloth - Vertical. Tests on treated fabric are the basis for selecting a maximum 5 in. char length in evaluating the carrier fabric. Test data on sample fabric averaged 4 1/4 inches char length with a range of ± 1/2 inch in eight data points. The fabric did not char or flame while the methane flame impinged upon the vertically mounted specimens. The fabric did melt away and shrink back from the heat of the flame.
Six chemical companies were solicited to provide treatments for the carrier material. Two were found to have explicitly durable FR treatments, one listing durability to launderings and dry cleanings. These are:

Eastern Color & Chemical Co.  
(ECCO Flameproof PE-100)  
35 Livingston St.  
Providence, RI 02940

Apollo Chemical Corp.  
(Bar Flame PCR)  
P.O. Box 2176  
Burlington, NC 27215

Both have been found acceptable. Both should result in sample tests with no afterburn upon removal of the ignition source and no plastic drip. One company (not listed) reported that the fabric passed the test with no treatment. Other tests conducted gave values up to 5 inches char length. The fuel contribution to a fire is reasonably low due to the low density of the mesh fabric. The FR treatments can be applied by standard industrial means, e.g. pad on from an aqueous solution and cure/tenter at 300-350°F.

D. Fabric Coloration

Should the need to arise, the polyester can be dyed by disperse dyes. The coloration may be used for carrier identification or visibility. Past experience shows that industrial dyeing processes have negligible affect on fabric strength. The FR treatment should be padded on after dyeing, and cured with a tenter frame to hold dimensions.
E. Carrier Geometry

Tests were conducted initially by NWSC, Crane on four bag geometries when loaded:

1-1 Zig-Zag Flat Lay - 11 1/8 inch width
2-1 Planar Flat Lay - 12 1/2
3-2 Planar Flat Lay - 17 1/8
- Tetrahedral Column - 13

These sample carriers were constructed of plain polyester mesh fabric. The 11 1/8 flat width planar Zig-Zag was selected as the more conformable geometry for ease of packing in a container. It will also pass most easily through a 15 inch x 23 inch opening. A length of 58 inches was selected by NWSC, Crane.

Later tests on the FR treated fabric which is somewhat stiffer, led to adoption of the following outside, flat dimensions:

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Dimensions, inches</th>
<th>Filled Length, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 Spheres</td>
<td>12 1/4 x 58</td>
<td>(less than) 48</td>
</tr>
<tr>
<td>9 Spheres</td>
<td>12 1/4 x 37 1/2</td>
<td>27 1/2</td>
</tr>
<tr>
<td>8 Spheres</td>
<td>12 1/4 x 34 1/2</td>
<td>24</td>
</tr>
</tbody>
</table>

Packing a 11 1/8 inch carrier resulted in a difficult to pack and less conformable structure. This could interfere with achieving a good packing fraction during actual storage of the filled carriers.
F. Carrier Seaming

To have seam strength equal to or surpassing body strength in the carrier, the following details of sewing were established. Seam type 504 or 505 overedge stitch of Fed. Std. 751A provides strength, and covers the exposed fabric edge.

Two seams, one over or on top of the other, provide the necessary security for the seam. Testing across seams showed no seam failures at the tensile loads given earlier, but jaw slip in the testing machine prevented testing to break. The three thread overedge stitch was formed from 1000 denier yarns. The carrier is knitted in the tested constructions from 1000 denier primary yarns on two guide bars and a smaller yarn on a third bar. There is actually more yarn in the seam than in the body of the fabric.

The edge seams and a final closure seam can be made with sewing machines such as the following:

MERROW Model M-3DWG-3
JUKI Model 2504

Both of these are three thread overedge seam machines.

CONCLUSIONS

A viable FR treated carrier fabric has been described. The report attempted to give reasons for design choices in selection of fiber and fabric parameters. Accompanying this report are a specification documents for the fabric and also specifications for machinery to close the carrier.
Specification Statements for a
Flame Retardant Treated Knit Carrier

1. Scope

1.1 This specification covers requirements for fiber and fabric properties, carrier dimensions and quality assurance provisions for a flame retardant treated knit carrier. The method of seaming edges of the carrier is also specified.

2. Applicable Documents

2.1 The following documents of the issue in effect on the date for invitation for bids, or request for proposals, form a part of this specification to the extent given herein.

2.1.1 Documents Referenced

A. Federal Standard 191A, Textile Test Methods
B. Federal Standard 751A, Stitches, Seams and Stitchings

2.1.2 Documents Containing Pertinent Information

A. MIL-T-63072(AR) Specification for Thread. Polyester
B. MIL-STD-1491 Glossary of Knitting Imperfections
F. Warp Knitting, D.F. Paling, Harlequin Press, Manchester (Eng), (1965)
3. Requirements

3.0 Definitions

A. Warp Knit - a method of knitting whereby the formation of knit loops progresses sequentially along a fabric wale. Wales are generated from continuous strands of yarn.

B. Course - a row of knit loops formed across the width of the fabric.

C. Wale - a column of knit loops formed by a needle down the length of the fabric.

D. Mesh Hole - an intentional hole in a warp knit fabric larger than a knit loop by a factor of three or more and created by guiding warp yarn to selected needles in a preselected pattern.

E. Denier - the mass in grams of a nine (9) kilometer hank or skein of fiber or yarn.

F. Tenacity - the breaking force of a fiber in units of grams-force per denier.

3.1 Description - The knit carrier shall be formed from high porosity flat fabric, cut, and seamed along two or three edges (a fold may replace one edge seam) to produce a tubular carrier, open on one end and closed on the other. The flat width and length shall be per section 3.2.4. Upon being filled, the objective is that the carrier will contain and constrain seventeen (17) approximately spherical objects, fourteen (14) centimeters (5.5 inches) in diameter in a manner which facilitates handling and then packing in hexagonal close packed layers.

3.2 Construction

3.2.1 Fiber - The knitting yarn shall be a continuous filament polyester suitable for warp knitting, and have a tenacity of at least 4.5 grams per denier.
3.2.2 Warp Knit Fabric - The fabric shall be produced on a Raschel knitting machine in an open mesh pattern with three or more guide bars delivering yarn to the needles. For reference, a mesh hole diameter may be typically four to eight millimeters (0.15 inches to 0.30 inches) formed by knit columns of 0.75 to 2.5 millimeters (0.03 inches to 0.10 inches) width. The above numbers are approximate and are for reference only in describing this Raschel mesh fabric. Fabric width and length shall be sufficient as to enable production of carriers with edge seams only on two lateral edges and across the bottom, and may be sufficiently wide to allow folding a double width piece of fabric such that only one lateral seam is required along with the bottom seam.

3.2.3 Fabric Properties - The measured fabric properties and tolerances pertinent to carrier function are enumerated as follows:

A. Areal density - 0.36 lbs/yd² ± 5%
B. Mesh hole density - 17 holes/in.² ± 3
C. Wales (or pattern legs) per inch - 7 wales/in. ± 1.5
D. Courses (or stitches) per inch - 21 courses/in ± 3
E. Ball burst strength - 100 lbs. minimum
F. Tensile Strength - 120 lbs. minimum, when tested along length (wale wise) direction; or along cross (course wise) direction.
G. Flame Retardancy - vertical flame test pass of 5.0 inches char length maximum and no afterburn.

Test methods for establishing the above properties include the following:

Federal Test Method Standard No. 191A:
Method 5120 Strength of Cloth; Ball Bursting Method
Method 5070 Wales and Courses in Knit Cloth
Method 5100 Breaking Strength of Cloth; Grab Method
Method 5041 Determination of Weight of Textile Material; Small Specimen Method
Method 5903 Flame Resistance of Cloth; Vertical
3.2.4 Carrier Construction - The sewing of the carrier edge seams shall be by a three thread overedge stitch such as Federal Standard 751-A type 504 or type 505 stitch. Each thread shall be 1000 denier polyester (see definitions in Section 3.0 and Federal Std. 191, Method 4021 for determination of denier).

The carrier flat finished outside dimensions shall be:

- Width - 12 1/4 inches ± 3/8 inch
- Length - 58 inches ± 1/2 inch

The carrier may be formed from two pieces of mesh knit fabric seamed along two edges and the bottom. The seaming shall consist of two continuous passes of the overedge stitch along side, bottom and side with a backtack at the finished end of seaming. Alternately, the carrier may be formed from a single piece of mesh knit fabric of double width, folded, and then seamed along one edge and the bottom. As with the two piece carrier construction, the edge and bottom shall consist of two passes of the overedge stitch and backtack of the finish seam end. The top may optionally be finished with a single overedge stitch around the open end for the full circumference and is not closed. Federal Standard 751-A also defines the fabric seam geometry. This specification does not require specific fabric seams, but the simple SSa seam has been found to perform satisfactorily.

3.3 Defects

3.3.1 Knots - Yarn knots shall not be considered as defects.

3.3.2 Misformed loops - An unintentional missed stitch in the pattern repeat is a defect but shall be permitted if occurrences are separated by more than one pattern repeat and if there are no more than two occurrences per fabric panel in the carrier.

3.3.3 Yarn Breaks - A yarn break in the body of a carrier panel is not allowed and shall cause rejection of that carrier item.
3.3.4 Repairs - Repairs to the carrier panels are not allowed in new items. Repairs to carriers placed in use and when necessary shall be by a single overedge stitch as given in 3.2.4 for edge seaming.

3.4 Workmanship - the carrier fabric shall be constructed using the best knitting practices. Individual fabric panels shall be clean with no oil or grease soaked regions. The fabric shall be handled with the care normally given quality knit products to avoid fabric damage and unnecessary contamination.


4.1 General Quality Assurance Provision - The supplier shall be responsible for the performance of inspection to assure the quality required by this specification.

4.1.1 Submission of Product - At the time a completed lot of product is submitted to the Government for acceptance, the contractor shall supply the following information accompanied by a statement which attests that the information provided is correct and applicable to the product being submitted:
   A. A statement that the lot complies with all technical and quality assurance requirements.
   B. The specification number and date.
   C. Number of items in the lot.
   D. Date submitted.

The statement shall be signed by a responsible agent of the contractor.

4.1.2 Government Verification - Using the specification and other contractual documents, the Government inspector shall verify the operations and inspection functions performed by the contractor. Verification will be performed to the extent necessary to assure compliance with contractual requirements.
4.2 Inspection Provisions

4.2.1 Examination - The sampling plan and procedure for the following classification of defects shall be in accordance with inspection level I, Table I of MIL-STD-105.

4.2.1.1 Flame Retardant Carrier

<table>
<thead>
<tr>
<th>Categories</th>
<th>Defects</th>
<th>Method of Inspection</th>
<th>Code No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical:</td>
<td>None Defined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major:</td>
<td>AQL 0.40 percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101.</td>
<td>Length</td>
<td>Gage</td>
<td>01001</td>
</tr>
<tr>
<td>102.</td>
<td>Width</td>
<td>Gage</td>
<td>01002</td>
</tr>
<tr>
<td>103.</td>
<td>Yarn Break</td>
<td>Visual</td>
<td>01003</td>
</tr>
<tr>
<td>104.</td>
<td>Repair Seam in Fabric Panel</td>
<td>Visual</td>
<td>01004</td>
</tr>
</tbody>
</table>

| Minor:       | AQL 1.00 percent         |                      |          |
| 201.         | Oil or Grease Stain      | Visual               | 01005    |
| 202.         | Evidence of Poor Workmanship | Visual           | 01006    |

5. Preparations for Delivery

5.1 Packing and Marking - The encasement sleeves shall be packed and marked in accordance with Specification MIL-P-10025.

6. Notes

6.1 Ordering Data - Procurement documents shall specify the following:

A. Title, number and date of this specification

6.2 Inspection Code Numbers - The five digit code numbers assigned to the inspections herein are to facilitate future data collection and analysis by the Government.
The planar packing arrangement which yields the greatest packing efficiency is the hexagonal close packed geometry. This is a central circle surrounded by six circles, all touching on two edges as is illustrated below.

For a single layer of spheres, the best packing arrangement is also hexagonal close packing. While planar circles can be shown to pack with an efficiency of 0.91, this is not true of spheres. Planes of spheres can nest one within the other such that the center to center distance is $\sqrt{6} \frac{d}{3}$, where $d$ is the diameter of one sphere. The value, $\sqrt{6} \frac{d}{3}$, is also the height of a tetrahedron whose edges are of length $d$.

Given a large volume compared to the volume of one sphere into which the spheres are to be packed, the edge effects, e.g. imperfect packing of the layer at the container wall, are negligible. Then for a layer of $N$ spheres length by $N$ spheres width, the total volume available in that layer is length x width x height = $Nd x \sqrt{6N} \frac{d}{3} Nd x \sqrt{6} \frac{d}{3} = 2 N^2 d^3/3$.

The volume of one sphere is $\frac{d^3}{6}$. For the $N x N$ layer, there are $N^2$ balls. The total volume occupied by balls in that layer is $\pi N^2 \frac{d^3}{6}$.

The packing efficiency for that layer then is the volume occupied by balls divided by the total volume available. This is $\pi N^2 \frac{d^3}{6}$ divided by $2 N^2 d^3/3$ or $\frac{\pi}{4} = 0.785$, the packing efficiency in one repeating plane.
Thus, the anticipation should be that due to edge effects and human errors, any real packing of sphere will have a packing efficiency less than 0.785. If the spheres have irregular surfaces, and the diameters are outer diameters, then packing improvements can be had.

Note that 0.785 is a volume packing efficiency. The total volume needed to contain N balls will be approximately $2N \frac{d^3}{3}$. 
I. Equipment for Closing Carrier

Two Machines for producing a three thread overedge stitch are:

a.) JUKI Model 2504
    Source: Lewis Sales (404) 457-3183

b.) MERROW Model M-3DWG-3
    Source: Merrow Sales (404) 621-9185

The sources are local to Atlanta, GA and the southeast region. Additional local sources throughout the country of these machines are available.
Schematic of Carrier

I. Primary Carrier

The primary carrier contains seventeen (17) spherical objects of approximately 5.25 inches diameter each. The following sketch shows the outline of the flame retardant treated carrier when laid flat. Measurements are outside dimensions on the finished carrier and are made with the carrier in a relaxed state, i.e. the knit fabric is not stretched in lengthwise or crosswise directions.

![Schematic of Carrier](image)

**FIGURE 1. SCHEMATIC OF CARRIER**

The packed length of this carrier is such that the packed carrier will fit within a 48 inch wide space.

II. Half Length Carrier

There may exist a need for a half length (when packed) carrier. The two options are to contain a.) eight (8) spheres or to contain b.) nine spheres. The carrier for these are outlined below.

a.) Eight (8) sphere carrier

The eight sphere carrier is constructed as per Figure 1 except that the final length is 35 1/2 ± 1/2 inches. This configuration is such that the packed carrier will fit within a 23 1/2 inch wide space.

b.) Nine (9) sphere carrier

The nine sphere carrier is constructed as per Figure 1 except that the final length is 37 1/2 ± 1/2 inches. This configuration is such that the packed carrier will fit within a 27 1/2 inch wide space.
LIST OF SOURCES FOR CARRIER PRODUCTION

The following companies have capabilities in the areas of raschel knitting, sewing, and FR treatment of fabric:

1. Southern Mills
   6501 Mall Blvd.
   Union City, GA 30291

2. Burlington Industries
   3330 W. Friendly Ave.
   Greensboro, NC 21207

   Iron Ore Rd.
   P.O. Box 1926
   Spartanburg, SC 29304

4. J. P. Stevens & Co.
   Stevens Tower
   1185 Ave. of Americas
   New York, NY 10036