Radiation-Crosslinked, Modified, Chlorinated Polyolefin Blend Jacketed Multiconductor Cables

1. SCOPE

1.1 DESCRIPTION

This specification covers requirements for multiconductor cables jacketed with a radiation-crosslinked Thermofit® NT-FR Tubing compound. This compound is controlled by Raychem Specification RT-511, which contains the appropriate material qualification tests. Thus, this specification is limited to construction and process-dependent requirements only (quality conformance inspection).

1.2 TEMPERATURE RATING

The cable jacket material covered by this specification is rated from -55ºC to 115ºC. The operational temperature of a finished cable may be limited by the internal materials or components selected, or it may be operational at higher temperatures for short durations depending on the application. It is the responsibility of the customer to determine the suitability of the final product for the application.

1.3 CABLE DESIGNATION

Cables shall be identified by a combination of digits and letters in accordance with the applicable specification sheet.

2. APPLICABLE DOCUMENTS

2.1 GOVERNMENT-FURNISHED DOCUMENTS

The following documents, of the issue in effect on date of invitation for bid or request for proposal, form a part of this specification to the extent specified herein.

2.1.1 Department of Defense

SPECIFICATIONS

MIL-C-24640 (10 August 1984 + Amendment 3)	Cable, Electrical, Lightweight for Shipboard Use, General Specification for
MIL-C-85485	Cable, Electric, Filter Line, Radio Frequency Absorptive

STANDARDS

FED-STD-228	Cable and Wire, Insulated; Methods of Testing
MIL-STD-1916	DOD Preferred Methods for Acceptance of Product

(Copies of Department of Defense documents may be obtained from the Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.)

2.2 OTHER PUBLICATIONS

The following documents, of the issue in effect on date of invitation for bid or request for proposal, form a part of this specification to the extent specified herein.

2.2.1 American Society for Testing and Materials (ASTM)

D 3032	Standard Methods of Testing Hookup Wire Insulation

(Copies of ASTM publications may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103.)

2.2.2 National Electrical Manufacturers Association (NEMA)

WC 27500	Standard for Aerospace and Industrial Electrical Cable

(Copies of NEMA publications may be obtained from the National Electrical Manufacturers Association, 1300 N. 17th Street, Rosslyn, Virginia 22209.)

2.2.3 Tyco Electronics Corporation

Specification RT-511	Thermofit® NT-FR Tubing, Neoprene, Fluid Resistant, Flexible, Heat-Shrinkable

(Copies of Tyco Electronics documents may be obtained from Tyco Electronics Corporation, 300 Constitution Drive, Menlo Park, CA 94025.)

3. REQUIREMENTS

3.1 GENERAL REQUIREMENTS

3.1.1 Cable Properties

The properties of finished cables are indexed in Table I herein and further detailed in Section 3. Quality groups are defined in paragraph 4.2.1.

TABLE I
PROPERTIES OF FINISHED CABLE

Examination or Test	Requirement	Procedure	Quality Group
Accelerated Aging	3.5.1, 175ºC for 4 hours	4.3.1	1
Attenuation	Specification sheet	MIL-C-24640	1
Cabling	Specification sheet and 3.5.2	4.3.12	1
Capacitance	Specification sheet	MIL-C-24640	1
Characteristic Impedance	Specification sheet	4.3.2	1
Color Codes and Methods	3.5.3	4.3.12	1
Conductor and Shield Continuity	3.5.4	4.3.3	2
Conductor and Shield Resistance	Specification sheet	4.3.4	1
Construction and Materials	Specification sheet, 3.3 and 3.4	4.3.12	1
EMP Response	Specification sheet	MIL-C-24640	1
Finished Cable Diameter	Specification sheet	ASTM D 3032, Section 15	1
Identification of Finished Cable	3.5.5	4.3.12	1
Insulation Resistance	Specification sheet and 3.5.6	4.3.5	1
Jacket Concentricity	3.5.7	ASTM D 3032, Section 16	1
Jacket Flaws	3.5.8	4.3.6	2
Jacket Tensile Strength and Elongation	1300 psi min., and 200% min.	4.3.7	1
Jacket Thickness	Specification sheet and 3.5.9	ASTM D 3032, Section 15	1
Shield Construction and Coverage	3.4.2	WC 27500	1
Strength Member Breaking Stress	Specification sheet and 3.5.10	4.3.8	1
Surface Transfer Impedance	Specification sheet and 3.5.11	4.3.9	1
Voltage Withstand (Dielectric)	Specification sheet and 3.5.12	4.3.10.1	2
Weight	Specification sheet	4.3.11	1
Workmanship	3.5.13	4.3.12	1
Wraps	3.4.3	4.3.12	1

3.1.2 Specification Sheets

The requirements for the component wire and finished cable furnished under this specification shall be as specified herein and in accordance with the applicable specification sheet. In the event of discrepancy between this specification and the requirements of the applicable specification sheet, the requirements of the specification sheet shall govern.

3.1.3 Components

Unless otherwise specified, component wires or cables shall be as specified in the applicable specification sheet. Components shall meet their own specification requirements prior to cabling.

3.2 CLASSIFICATION OF REQUIREMENTS

The applicable requirements are classified herein as follows:

Requirement	Paragraph
Materials	3.3
Construction	3.4
Detail Requirements	3.5

3.3 MATERIALS

Materials not specifically designated herein shall be of the quality and form best suited for the purpose intended. Unless otherwise specified, the materials shall meet the following requirements:

3.3.1 Shield Material

Shield material shall be as shown on the specification sheet and shall meet the material requirements for that type as specified in WC 27500.

3.3.2 Cable Jacket Material

Cable jacket material shall be be in accordance with Tyco Electronics Specification RT-511.

3.4 CONSTRUCTION

Construction of the finished cable shall be as specified herein and in the applicable specification sheet.

3.4.1 Component Wire

Component wires shall be the type and size as specified on the applicable specification sheet.

3.4.2 Shield Construction and Coverage

3.4.2.1 Braided Shields

The shield shall meet the requirements of the applicable specification sheet. Unless otherwise specified, the shield coverage shall be 85 percent, minimum. The shield shall be free of irregularities, discontinuities and whole braid splices. Shield coverage and braid angle shall be determined in accordance with WC 27500 when applicable.

3.4.2.2 Foil Shields and Drain Wires

Foil shields and drain wires shall meet the requirements of the applicable specification sheet.

3.4.3 Wraps

Wrap tapes, where specified on the applicable specification sheet, shall be applied with an overlap of 25 percent, minimum, and shall meet the material and construction requirements of the applicable specification sheet. Overlap is defined as the percentage of tape width covered by successive turns of tape.

3.4.4 Jacket

The jacket shall be extruded concentrically over the cable core. The jacket shall meet the applicable requirements of Table I and the applicable specification sheet, and shall be removable without damage to the underlying shield or components.

3.5 DETAIL REQUIREMENTS

Finished cable shall conform to the requirements of this section and those of the applicable specification sheet.

3.5.1 Accelerated Aging

When specimens of the finished cable jacket are aged at the time and temperature stated in Table I and tested in accordance with 4.3.1, the tensile strength and elongation retention shall be 60 percent, minimum, of the original values.

3.5.2 Cabling

3.5.2.1 Configuration

The required number of components as specified in the applicable specification sheet shall be cabled together with a left-hand lay. For cables having multiple layers, the outer layer shall be left-hand and the inner layer or layers may be either right-hand or left-hand lay. The lay length of the components in the outer layer shall be not less than eight nor more than sixteen times the outside diameter of the cable bundle.

3.5.2.2 Cabling Sequence

In the case of cables having more than one layer of components, the component numbering sequence, when applicable, shall be from the innermost to the outermost; i.e., component number 1 shall be the center component (or one of the center components where two or more are used as a center) of the concentric layup.

3.5.2.3 Fillers and Binders

Fillers and binders shall be used as necessary to produce a firm round cable. Filler and binder material shall be moisture resistant and shall be compatible with all other cable components.

3.5.3 Color Codes and Methods

3.5.3.1 Wire and Component Identification - General

Individual wires or individual wires of component groups shall be identified in accordance with the applicable specification sheet. Where colored insulation, stripes, bands, or other marks are used, color designations are as follows:

Number	Color	Number	Color
0	Black	5	Green
1	Brown	6	Blue
2	Red	7	Violet
3	Orange	8	Gray
4	Yellow	9	White

An “L” suffix on the number indicates a lighter variation; e.g., 2L is pink. Where printed characters are used for identification, the vertical axes of the characters may be either perpendicular or parallel to the longitudinal axis of the wire. The spacing between legends shall be 3 inches *(76 mm)*, nominal. Character height shall be proportional to the substrate diameter as follows:

Diameter Range		Height of Character (Approx.)	
Inch	*mm*	Inch	*mm*
0.045 to 0.070	*1.1 to 1.8*	0.025	*0.64*
0.070 to 0.095	*1.8 to 2.4*	0.031	*0.79*
0.095 to 0.115	*2.4 to 2.9*	0.047	*1.20*
0.115 to 0.200	*2.9 to 5.1*	0.063	*1.60*
0.190 to 0.250	*4.8 to 6.4*	0.078	*2.00*
0.235 to 0.375	*6.0 to 9.5*	0.094	*2.40*
0.375 and larger	*9.5 and larger*	0.125	*3.20*

3.5.3.2 Wire and Component Identification - Pilot and Direction Method

When specified, the following identification requirements shall apply for each layer specified on the applicable specification sheet:

a.) Multiconductor Cables:
- 2/Conductor—red and blue
- 3/Conductor—red, blue and white
- Others—red and blue conductors adjacent in each layer with remaining conductors white.

b.) Multi-Pair Cables:
- Center Pair—red/blue
- Red/black and blue/black pairs adjacent in each layer with remaining pairs white/black.

c.) Multi-Triad Cables:
- Each triad to be red/blue/white with the white wire in each triad numbered. In the case of jacketed triads, the jacket shall be numbered instead of the white component.

3.5.4 Conductor and Shield Continuity

Prior to shipment, one hundred percent of all finished cable shall be tested for continuity in accordance with 4.3.3. There shall be no indication of discontinuity in any of the component wires or shields, as applicable.

3.5.5 Identification of Finished Cable

The outer surface of the cable jacket shall be printed in accordance with the applicable specification sheet. The legend shall be printed at 12-inch *(305-mm)*, nominal, intervals in white ink on black jackets, or in an ink color providing suitable contrast on jackets with colors other than black. The mark shall be both durable and legible.

3.5.6 Insulation Resistance

When finished cable is tested in accordance with 4.3.5, the insulation resistance of the cable components shall meet the requirements of the specification sheet.

3.5.7 Jacket Concentricity

When finished cable is tested in accordance with ASTM D 3032, Section 16, the cable jacket concentricity shall be 70 percent, minimum.

3.5.8 Jacket Flaws

When the finished cable has an overall shield, 100 percent of the cable shall pass the jacket flaws test of 4.3.6. Jacket flaws testing shall be performed during the final winding of shipment spools or reels at 3.0 kV (rms) at a frequency of 50 Hz, 60 Hz, or 3 kHz.

3.5.9 Jacket Thickness

Jacket thickness shall meet the requirements of the specification sheet. The minimum jacket thickness when tested in accordance with ASTM D 3032, Section 15, shall be no less than 80 percent of the specified nominal. Nominal jacket thickness is defined as half the difference between nominal cable diameter and the nominal diameter of the underlying layer.

3.5.10 Strength Member Breaking Stress

When tested in accordance with 4.3.8, strength members shall meet the requirements on the specification sheet prior to cabling.

3.5.11 Surface Transfer Impedance

Where optimized or supershields are specified on the applicable specification sheet, the surface transfer impedance (shielding effectiveness) shall meet the requirements listed below (measured at a single frequency of 30 MHz), or the requirements of the specification sheet for a swept frequency measurement, when tested per 4.3.9.

Maximum surface transfer impedance, in milliohms per meter at 30 MHz, shall be as follows when the diameter under the shield is:

Shield Construction	< 0.30 inch	≥ 0.30 inch
Single Optimized	100	50
Double Optimized	10	5
Supershielded (2 shields, 1 foil)	0.10	0.05
Double Supershielded (3 shields, 2 foils)	0.01	0.01

3.5.12 Voltage Withstand (Dielectric)

When tested in accordance with 4.3.10.1, the cable shall withstand the following voltages, except for coaxial cables which shall be tested in accordance with their own specification sheet:

Connection	Voltage (rms)
Wire-to-wire	1500
Wire-to-shield	1500
Shield-to-shield (extruded jackets)	1000
Shield-to-shield (sealed tape jacket)	500
Shield-to-shield (unsealed tape jackets)	n/a

3.5.13 Workmanship

All details of workmanship shall be in accordance with high-grade wire and cable manufacturing practice. The insulation and jacket shall be free of cracks, splits, irregularities, and imbedded foreign material.

4. QUALITY ASSURANCE PROVISIONS

4.1 RESPONSIBILITY FOR INSPECTION

The supplier is responsible for the performance of all inspection tests specified herein. The supplier may utilize his own or any other inspection facility and services acceptable to the buyer. Inspection records of the examinations and tests shall be kept complete and available to the buyer as required.

4.2 QUALITY CONFORMANCE INSPECTION

Quality conformance inspection shall consist of the examinations and tests listed in Table I and described under "Test Methods" (4.3). Quality conformance inspection shall be performed on every lot of finished cable manufactured under this specification. Those tests that are of such a nature that they cannot be performed on the finished cable are performed at an appropriate stage during manufacture.

4.2.1 Sampling for Quality Conformance Inspection

Sampling for quality conformance inspection shall be in accordance with MIL-STD-1916 and the following:

4.2.1.1 Sample Unit (Group 1 Tests)

The sample unit for Group 1 tests, except for the Group 1 insulation resistance test, shall consist of a single piece of finished cable chosen at random from the lot and of sufficient length to permit all applicable examinations and tests.

4.2.1.1.1 *Sample Unit for Insulation Resistance Test (Group 1)*

The sample unit for the Group 1 insulation resistance test shall be a specimen at least 25 feet *(7.6 m)* in length selected at random from finished cable. It is optional whether the specimen is tested on the reel or removed from the lot for the test, provided the length of the specimen can be determined.

4.2.1.2 Acceptance for the Group 1 Tests

For Group 1 tests, including the insulation resistance test, the selected sample shall meet all applicable requirements of Table I.

4.2.1.3 Sampling and Acceptance for the Group 2 Tests

The sample for the Group 2 tests shall be 100 percent of the finished cable, and every length of the cable shall be fully tested. Portions showing breakdown and ends or portions not subjected to these tests shall be removed and the remaining lengths tested until no failure occurs.

4.2.2 Nonconforming Inspection Lots

All lots found unacceptable under initial quality conformance inspection shall be reviewed and reworked in accordance with established internal procedures.

4.3 TEST METHODS

4.3.1 Accelerated Aging

Specimens of the finished cable jacket shall be prepared and conditioned in accordance with Method 4031 of FED-STD-228 for the time and temperature specified in Table I. Tensile strength and elongation shall be determined in accordance with 4.3.7.

4.3.2 Characteristic Impedance

4.3.2.1 Method A

This method shall only be used for cables whose nominal impedance is within 20 percent of Z_{ref}, where Z_{ref} is the impedance of the calibrated reference air line (CRAL). (For a 50-ohm CRAL, the measurable range of cables is 40-60 ohms.) This method cannot be used for determination of characteristic impedance at a single given frequency.

4.3.2.1.1 *Method A - Specimen Preparation*

For a coaxial cable, attach suitable connectors to both ends. For twisted pairs, the measurement shall be made wire-to-wire. Designate one wire as the inner conductor and the other wire as the outer conductor and attach suitable connectors to both ends.

4.3.2.1.2 *Method A - Apparatus*

The apparatus shall consist of a Time Domain Reflectometer (TDR) with a maximum rise time of 150 picoseconds and a minimum reflection coefficient sensitivity of .005. A calibrated reference air line (CRAL) of suitable impedance and connectors shall be used.

4.3.2.1.3 *Method A - Procedure*

Attach CRAL to TDR output. Designate the resulting trace as "Z_{ref}" and adjust the horizontal magnifier control unit until Z_{ref} extends through at least six horizontal divisions. The sample cable shall then be attached and the resulting Z_{ref} trace shall be designated as "Z_c". With cable attached, the REFLECTION COEFFICIENT dial shall be adjusted so that Z_{ref} and Z_c are both on the graticule portion of the screen, but as far apart vertically as possible. Record the setting on the dial as "A_{RC}". Determine the vertical spacing between Z_{ref} and Z_c in vertical divisions and designate as "ρu". If Z_{ref} is higher than Z_c, then ρu is negative. If Z_{ref} is lower than Z_c, then ρu is positive.

Define "ρ" as: $$\rho = \rho u \, . \, A_{RC}$$

Characteristic impedance, Z_0, shall be determined from the following formula:

$$Z_0 = Z_{ref} \frac{1 + \rho}{1 - \rho}$$

4.3.2.2 Method B

This method is appropriate for determination of the characteristic impedance of cables at a given frequency which, unless otherwise specified, shall be 1 MHz.

4.3.2.2.1 *Method B - Procedure*

Using a 1 MHz bridge, determine the capacitance (C) per MIL-C-24640. The end of the specimen used to determine the capacitance shall then be shorted and the inductance (L) of the specimen shall be determined using a 1 MHz bridge. Determination of the capacitance and inductance may also be made at other specified frequencies by use of a suitable bridge. The characteristic impedance at 1 MHz, or other specified frequency, shall be determined from the relation:

$$Z_0 = \sqrt{L/C}$$

Where:

Z_0 = characteristic impedance in ohms
L = inductance in henries
C = capacitance in farads

For multi-pair cables, the capacitance (C) shall be the mutual capacitance (C_m).

4.3.3 Conductor and Shield Continuity

To establish continuity, 25 volts DC, maximum, shall be applied to both ends of each conductor and shield of the cable through an appropriate indicator, such as an ohmmeter, light, or buzzer. The test voltage may be applied to the conductors and shields individually, or in a series.

4.3.4 Conductor and Shield Resistance

The conductor or shield resistance of the finished cable shall be tested in accordance with FED-STD-228, Method 6021, except that it shall be tested dry.

4.3.5 Insulation Resistance

Insulation resistance shall be measured on samples of finished cable at least 25 feet *(7.6 m)* in length. A DC potential between 200 and 500 volts shall be applied between each conductor or shield in the cable and all the other conductors and shields. The insulation resistance value shall be measured at any time after the application of the DC potential up to a maximum of 5 minutes. A direct-reading megohmmeter may also be used.

4.3.6 Jacket Flaws

Finished cable shall be passed through a chain electrode spark test device using the required voltage and frequency. The shield shall be grounded at one or both ends. The electrode shall be of a suitable bead chain or fine mesh construction that will give intimate metallic contact with practically all of the jacket surface. Electrode length and speed of specimen movement shall be such that the jacket is subjected to the test voltage for a minimum of 0.2 second. Any portion showing breakdown shall be cut out, including at least 2 inches *(51 mm)* of cable on each side of the failure.

4.3.7 Jacket Tensile Strength and Elongation

Specimens of the finished cable jacket shall be tested in accordance with Methods 3021 and 3031 of FED-STD-228 with one-inch *(25-mm)* bench marks, one-inch *(25-mm)* jaw separation, and a jaw separation speed of 2 inches *(51 mm)* per minute, unless otherwise specified on the applicable specification sheet. The thickness of the specimen shall be measured using a suitable micrometer.

4.3.8 Strength Member Breaking Stress

The breaking load of an entire strength member shall be tested by mounting a 10-inch *(254-mm)* sample in the tensile tester. Crosshead separation speed shall be 2 inches *(51 mm)* per minute. Special load-distributing grips designed for testing high-strength cords and yarns shall be used. The load required to break the sample shall not be less than that specified on the specification sheet.

4.3.9 Surface Transfer Impedance

The surface transfer impedance of the overall shield of finished cable shall be tested in accordance with MIL-C-85485, 4.3.9.1 and 4.3.9.2.

4.3.9.1 Specimen Preparation

The individual shields of shielded components, when present, shall be connected to the conductors, and the connected conductors and shields shall be “the conductor” as defined in MIL-C-85485, except on end “B” where only one conductor shall be “the conductor”, with all other conductors and individual shields of shielded components floating. When a measurement at a discrete frequency is specified, the specimen length shall be 0.7 meter *(27.6 inches)*, otherwise the length shall be 1.0 meter *(39.4 inches)*.

4.3.9.2 Determination of Compliance

The value of Z_t, as determined from measurements made in accordance with the above, shall not exceed the maximum specified values of Z_t as shown on the applicable specification sheet in any of the following ways:

a.) A single maximum value of Z_t may be specified at a discrete frequency or over a range of frequencies.

b.) The maximum value of Z_t over a range of frequencies may be specified by a plot of the maximum value of Z_t versus frequency.

4.3.10 Voltage Withstand

Voltage withstand tests shall be made using an AC source with a frequency of 50 or 60 Hz. The voltage specified shall be applied for 15 to 30 seconds, unless otherwise specified.

4.3.10.1 Voltage Withstand (Dielectric)

Voltage withstand (dielectric) tests shall be performed upon finished cable as described in 4.3.10.1.1, 4.3.10.1.2, or 4.3.10.1.3 as appropriate, with the voltage specified in 3.5.11 or the specification sheet, as applicable.

4.3.10.1.1 *Wire-to-Wire*

Wire-to-wire tests shall be conducted by applying the specified voltage to each conductor in turn with all the other conductors grounded. Any shields present shall be left unconnected from any conductors and from each other except as described in 4.3.10.1.2.

4.3.10.1.2 *Wire-to-Shield*

Wire-to-shield tests shall be conducted by applying the specified voltage to each conductor in turn with all shields grounded. When the specified voltages for wire-to-wire tests and wire-to-shield tests are identical, the tests may be combined and the common specified voltage shall be applied to each conductor in turn with all other conductors and shields connected together and grounded.

4.3.10.1.3 *Shield-to-Shield*

Shield-to-shield tests shall be conducted by applying the specified voltage to each shield in turn with all other shields grounded.

4.3.10.2 Voltage Withstand (Post-Environmental)

Voltage withstand (post-environmental) tests on the outer jacket shall be performed after the specified conditioning. The finished cable shall be immersed in a 5-percent, by weight, solution of sodium chloride in water at room temperature for at least one hour and, while the cable is still immersed, a voltage of 2.5 kV (rms) shall be applied between all the conductors and shields, tied together, and the water bath which shall be grounded. The voltage shall be applied for 1 minute.

4.3.11 Weight

The weight of each lot of finished cable shall be determined by Procedure I (4.3.11.1). Lots failing to meet the weight requirement of the applicable specification sheet when tested in accordance with Procedure I shall be subjected to Procedure II (4.3.11.2). All reels or spools failing to meet the requirements of the applicable specification sheet when tested to Procedure II shall be rejected.

4.3.11.1 Procedure I

A length of cable, sufficient to produce a measured weight to at least 3 significant figures, shall be weighed and converted to the weight per unit length shown on the applicable specification sheet.

4.3.11.2 Procedure II

The net weight of the finished cable on each reel or spool shall be obtained by subtracting the tare weight of the reel or spool from the gross weight of the reel or spool containing the finished cable. The net weight of cable on each reel or spool shall be divided by the accurately determined length of finished cable on that reel or spool and the resultant figure converted to pounds per 1000 feet *(kg/km)*. When wood or other moisture absorbent materials are used for reel or spool construction, weight determinations shall be made under substantially uniform conditions of relative humidity.

4.3.12 Examination of Product

All samples shall be examined carefully to determine conformance to this specification and to the applicable specification sheets with regard to requirements not covered by specific test methods.

5. PREPARATION FOR DELIVERY

5.1 PACKAGING AND PACKING

Cable shall be delivered wound on reels or spools in accordance with 5.1.1. Cable shall be wound on the reel or spool in such a manner that all ends are accessible.

5.1.1 Reels and Spools

Reels and spools shall be of a non-returnable type. Each reel or spool shall have an appropriate diameter for the respective cable size. In no case shall the barrel of the reel or spool have a diameter less than 12 times the nominal diameter of the finished cable. Reels and spools shall be suitably finished to prevent corrosion under typical storage and handling conditions.

5.1.2 Containers

Unless otherwise specified, cable shall be delivered in standard commercial containers so constructed as to ensure acceptance by common or other carrier for safe transportation to the point of delivery.

5.1.3 Marking of Shipments

All spool and reel labels shall be identified with the following information:

Manufacturer's Part Number
Lot Number
Quantity in Feet *(or Meters)*
Name of Manufacturer

6. NOTES

6.1 PRIMARY AND SECONDARY UNITS

Test requirements or parameters are originally developed using either English or Metric units. The original (primary) units are shown first with the converted values (secondary units) in parentheses. Secondary units are for reference only.