ANSI/ICEA S-93-639
NEMA WC 74

5-46kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy

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5-46kV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy

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Foreword

This Standards Publication for 5-46 kV Shielded Power Cable for the Use in the Transmission and Distribution of Electric Energy was developed by the Insulated Cable Engineers Association (ICEA) and approved by the National Electrical Manufacturers Association (NEMA).

ICEA/NEMA Standards are adopted in the public interest and are designed to eliminate misunderstanding between the manufacturer and the user and to assist the user in selecting and obtaining the proper product for his particular need. Existence of an ICEA/NEMA Standard does not in any respect preclude the manufacture or use of products not conforming to the standard. The user of this Standard is cautioned to observe any health or safety regulations and rules relative to the manufacture and use of cable made in conformity with this Standard.

Requests for interpretation of this Standard must be submitted in writing to:

Insulated Cable Engineers Association
P.O. Box 1568
Carrollton, GA 30112, USA

An official written interpretation will be provided once approved by ICEA and NEMA. Suggestions for improvements gained in the use of this Standard will be welcomed by the Association.

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Section 1
GENERAL

1.1 SCOPE

These standards apply to materials, constructions, and testing of 5000 volt to 46,000 volt shielded crosslinked polyethylene, and ethylene propylene rubber insulated wires and cables which are used for the transmission and distribution of electrical energy for normal conditions of installation and service, either indoors, outdoors, aerial, underground, or submarine.

1.2 GENERAL INFORMATION

These standards cover the requirements for conductors, the insulations and protective coverings and general constructional and dimensional details common to most standard shielded types of wires and cables. Constructions of specific types are covered in Section 10 or in other ICEA documents. Where a conflict exists between the requirements of Section 10, or other ICEA documents, and those of Sections 1 to 9 inclusive, the requirements of specific types shall apply. See Appendix A for complete titles and dates of ICEA publications and ASTM Standards to which reference is made in this publication. See Section 9 for test procedures not elsewhere referenced. Recommended minimum bending radii are given in Appendix I.

In classifying crosslinked insulations and jackets in these standards, the term "rubber" when used alone without further description shall mean synthetic rubber.

Insulation thicknesses are designated in terms of cable insulation levels (see 4.2).

In classifying jackets and sheaths in these standards, the term "jacket" refers to a continuous nonmetallic covering and "sheath" to a continuous metallic covering.

In these standards, most units are expressed in the English system. For information only, their approximate metric equivalents are included.

Requirements of a referenced ASTM standard shall be determined in accordance with the procedure or method designated in the referenced ASTM standard unless otherwise specified in this standard.

1.3 INFORMATION TO BE SUPPLIED BY PURCHASER

When requesting design proposals from cable manufacturers, the prospective purchaser should furnish the following information:

1.3.1 Characteristics of System on Which Cable is to be Used

1. Current - alternating or direct.
2. Frequency - hertz.
3. Normal operating voltage between phases or, in direct current, between conductors.
4. Number of phases and conductors.
5. Cable insulation level (see 4.2).
6. Minimum temperature at which cable will be installed.
7. Description of installation.
   a. In buildings.
   b. In underground ducts.

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c. Aerial.
    (1) On messenger in metal rings.
    (2) Preassembled.
    (3) Field spun.
d. Direct burial in ground.
e. Submarine.
f. Descriptions other than the foregoing.

8. Conditions of installation.
    a. Ambient temperature.
    b. Number of loaded cables in duct bank or conduit. Duct/conduit type, conduit (metallic or nonmetallic, magnetic/non-magnetic), size, number of loaded conduits/ducts, enclosed or exposed, and spacing between conduits/ducts.
    c. Load factor.
    d. Method of bonding and grounding of shields or sheaths.
    e. Wet or dry location.
9. Other special conditions.

1.3.2 Quantities and Description of Cable

1. Total number of feet, including test lengths, and shipping reel lengths if specific lengths are required.
2. Type of cable. Describe as single conductor, two-conductor, three-conductor, etc.
3. Rated circuit voltage, phase to phase.
4. Type of conductor - copper or aluminum.
5. Size of conductor. If conditions require other than standard stranding, a complete description should be given.
6. Type of insulation.
7. Thickness of insulation.
8. Type of shield.
9. Type of outer covering.
10. Maximum allowable overall diameter. When duct space is not limited, it is desirable not to restrict the overall diameter.
11. Method of conductor identification.
12. Special markings.

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Section 2
CONDUCTOR

2.0 GENERAL

Conductors shall meet the requirements of the appropriate ASTM standards referenced in this standard except that resistance will determine cross-sectional area as noted in 2.4 and diameters will be in accordance with 2.5.

Requirements of a referenced ASTM standard shall be determined in accordance with the procedure or method designated in the referenced ASTM standard unless otherwise specified in this standard.

The following technical information on typical conductors may be found in Appendix H:

a. Approximate diameters of individual wires in stranded conductors.
b. Approximate conductor weights.

2.1 PHYSICAL AND ELECTRICAL PROPERTIES

The conductors used in the cable shall be copper in accordance with 2.1.1 or aluminum in accordance with 2.1.2, as applicable, except as noted in 2.0. Conductors shall be solid or stranded. The outer layer of an uncoated stranded copper conductor may be coated to obtain free stripping of the adjacent polymeric layer. There shall be no moisture in stranded conductors in accordance with 9.20.

2.1.1 Copper Conductors

1. ASTM B 3 for soft or annealed uncoated copper.
2. ASTM B 5 for electrical grade copper.
3. ASTM B 8 for Class A, B, C, or D stranded copper conductors.
4. ASTM B 33 for soft or annealed tin-coated copper wire.
5. ASTM B 496 for compact-round stranded copper conductors.
6. ASTM B 784 for modified concentric lay stranded copper conductor.
7. ASTM B 785 for compact round modified concentric lay stranded copper conductor.
8. ASTM B 787 for 19 wire combination unilay-stranded copper conductors.
9. ASTM B 835 for compact round stranded copper conductors using single input wire constructions.

2.1.2 Aluminum Conductors

1. ASTM B 230 for electrical grade aluminum 1350-H19.
2. ASTM B 231 for Class A, B, C, or D stranded aluminum 1350 conductors.
3. ASTM B 233 for electrical grade aluminum 1350 drawing stock.
4. ASTM B 400 for compact-round stranded aluminum 1350 conductors.
5. ASTM B 609 for electrical grade aluminum 1350 annealed and intermediate tempers.
6. ASTM B 786 for 19 wire combination unilay-stranded aluminum 1350 conductors.
7. ASTM B 800 for 8000 series aluminum alloy annealed and intermediate tempers.
8. ASTM B 801 for 8000 series aluminum alloy wires, compact- round, compressed and concentric-lay Class A, B, C and D stranded conductors.
9. ASTM B 836 for compact round stranded aluminum conductors using single input wire constructions.

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2.2 OPTIONAL SEALANT FOR STRANDED CONDUCTORS

With the approval of the purchaser, a sealant designed as an impediment to longitudinal water penetration may be incorporated in the interstices of the stranded conductor. Compatibility with the conductor shield shall be determined in accordance with ICEA Publication T-32-645. Longitudinal water penetration resistance shall be determined in accordance with ICEA Publication T-31-610 and shall meet a minimum requirement of 5 psig.

2.3 CONDUCTOR SIZE UNITS

Conductor size shall be expressed by cross-sectional area in thousand circular mils (kcmil). The AWG equivalents for small sizes shall be found in Table 2-4. The metric equivalents for all sizes are found in Table 2-4 (Metric).

2.4 CONDUCTOR DC RESISTANCE PER UNIT LENGTH

The dc resistance per unit length of each conductor in a production or shipping length of completed cable shall not exceed the value determined from the schedule of maximum dc resistances specified in Table 2-2 when using the appropriate nominal value specified in Table 2-3 or 2-3 (Metric). The dc resistance shall be determined in accordance with 2.4.1 or 2.4.2.

Where the outer layer of an uncoated stranded copper conductor is coated, the direct current resistance of the resulting conductor shall not exceed the value specified for an uncoated conductor of the same size.

When a sample is taken from a multiple conductor cable, the resistance shall comply with the appropriate maximum resistance value specified for a single conductor cable.

2.4.1 Direct Measurement of dc Resistance

The dc resistance per unit length shall be determined by dc resistance measurements made in accordance with ICEA Publication T-27-581/WC 53 to an accuracy of 2% or better. If measurements are made at a temperature other than 25°C, the measured value shall be converted to resistance at 25°C by using the methods specified in ICEA T-27-581/NEMA WC53.

If verification is required for the direct-current resistance measurement made on an entire length of completed cable, a sample at least 1 foot (0.305 m) long shall be cut from that reel length, and the direct-current resistance of each conductor shall be measured using a Kelvin-type bridge or a potentiometer.

2.4.2 Calculation of dc Resistance Per Unit Length

The dc resistance per unit length at 25°C shall be calculated using the following formula:

$$R = K\frac{\rho}{A}$$

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Where:

R = Conductor resistance in Ω/1000 ft.
K = Weight increment factor, as given in Table 2-1.
ρ= Volume resistivity in Ω•cmil/ft., determined in accordance with ASTM B 193 using round wires
A = Cross-sectional area of conductor in kcmil, determined in accordance with T-27-581/NEMA WC-53.

When the volume resistivity is expressed in nanoohm meter (nΩ•m) and area is expressed in square millimeters (mm^2) the resistance is expressed in milliohm per meter (mΩ/m).

2.5 CONDUCTOR DIAMETER

The conductor diameter shall be measured in accordance with ICEA T-27-581/NEMA WC-53. The diameter shall not differ from the nominal values shown in Table 2-4 by more than plus or minus 2 percent.

Table 2-1
WEIGHT INCREMENT FACTORS*

Conductor Type/Size	Weight Factor (K)
Solid All Sizes	1
Concentric-lay Strand, Class A, B, C and D 8 AWG - 2000 kcmil >2000 - 3000 kcmil	 1.02 1.03
Combination Unilay Strand All Sizes	1.02
Concentric-lay Strand 8000 Series Aluminum All Sizes	1.02

* Based on the method specified in either ASTM B 8, ASTM B 496, ASTM B 400, ASTM B 231, ASTM B 786, ASTM B 787, or ASTM B 801 as applicable.

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Table 2-2
SCHEDULE FOR ESTABLISHING MAXIMUM DIRECT CURRENT RESISTANCE PER UNIT LENGTH OF COMPLETED CABLE CONDUCTORS LISTED IN TABLE 2-4

Cable Type	Maximum dc Resistance
Single Conductor Cables and Flat Parallel Cables	Table 2-3[a] Value Plus 2% (R max = R x 1.02)
Twisted Assemblies of Single Conductor Cables	Table 2-3[a] Value Plus 2% Plus An Additional 2% - For One Layer of Conductors (R max = R x 1.02 x 1.02)

[a] For conductor strandings or sizes not listed in Tables 2-3, the nominal direct current resistance per unit length of a completed single conductor cable shall be calculated from the factors given in Table 2-5 using the following formula:

$$R = \frac{f}{A} 10^{-3}$$

Where:

R = Conductor resistance in Ω/1000 ft.
f = Factor from Table 2-5
A = Nominal Cross-sectional area of conductor in kcmil

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Table 2-3
NOMINAL DIRECT CURRENT RESISTANCE IN OHMS PER 1000 FEET AT 25ºC
OF SOLID AND CONCENTRIC LAY STRANDED CONDUCTOR

Conductor Size AWG or kcmil	Solid			Concentric Lay Stranded*				
	Aluminum	Copper		Aluminum	Copper			
		Uncoated	Coated		Uncoated	Coated		
				Class A,B,C,D	Class B,C,D	Class B	Class C	Class D
8	1.05	0.640	0.659	1.07	0.652	0.678	0.678	0.680
7	0.833	0.508	0.522	0.851	0.519	0.538	0.538	0.538
6	0.661	0.403	0.414	0.675	0.411	0.427	0.427	0.427
5	0.524	0.319	0.329	0.534	0.325	0.338	0.339	0.339
4	0.415	0.253	0.261	0.424	0.258	0.269	0.269	0.269
3	0.329	0.201	0.207	0.334	0.205	0.213	0.213	0.213
2	0.261	0.159	0.164	0.266	0.162	0.169	0.169	0.169
1	0.207	0.126	0.130	0.211	0.129	0.134	0.134	0.134
1/0	0.164	0.100	0.102	0.168	0.102	0.106	0.106	0.106
2/0	0.130	0.0794	0.0813	0.133	0.0810	0.0842	0.0842	0.0842
3/0	0.103	0.0630	0.0645	0.105	0.0642	0.0667	0.0669	0.0669
4/0	0.0819	0.0500	0.0511	0.0836	0.0510	0.0524	0.0530	0.0530
250	0.0694	...	...	0.0707	0.0431	0.0448	0.0448	0.0448
300	0.0578	...	...	0.0590	0.0360	0.0374	0.0374	0.0374
350	0.0495	...	...	0.0505	0.0308	0.0320	0.0320	0.0320
400	0.0433	...	...	0.0442	0.0269	0.0277	0.0280	0.0280
450	0.0385	...	...	0.0393	0.0240	0.0246	0.0249	0.0249
500	0.0347	...	...	0.0354	0.0216	0.0222	0.0224	0.0224
550	...	...	...	0.0321	0.0196	0.0204	0.0204	0.0204
600	...	...	...	0.0295	0.0180	0.0187	0.0187	0.0187
650	...	...	...	0.0272	0.0166	0.0171	0.0172	0.0173
700	...	...	...	0.0253	0.0154	0.0159	0.0160	0.0160
750	...	...	...	0.0236	0.0144	0.0148	0.0149	0.0150
800	...	...	...	0.0221	0.0135	0.0139	0.0140	0.0140
900	...	...	...	0.0196	0.0120	0.0123	0.0126	0.0126
1000	...	...	...	0.0177	0.0108	0.0111	0.0111	0.0112
1100	...	...	...	0.0161	0.00981	0.0101	0.0102	0.0102
1200	...	...	...	0.0147	0.00899	0.00925	0.00934	0.00934
1250	...	...	...	0.0141	0.00863	0.00888	0.00897	0.00897
1300	...	...	...	0.0136	0.00830	0.00854	0.00861	0.00862
1400	...	...	...	0.0126	0.00771	0.00793	0.00793	0.00801
1500	...	...	...	0.0118	0.00719	0.00740	0.00740	0.00747
1600	...	...	...	0.0111	0.00674	0.00694	0.00700	0.00700
1700	...	...	...	0.0104	0.00634	0.00653	0.00659	0.00659
1750	...	...	...	0.0101	0.00616	0.00634	0.00640	0.00640
1800	...	...	...	0.00982	0.00599	0.00616	0.00616	0.00622
1900	...	...	...	0.00931	0.00568	0.00584	0.00584	0.00589
2000	...	...	...	0.00885	0.00539	0.00555	0.00555	0.00560
2500	...	...	...	0.00715	0.00436	0.00448	...	...
3000	...	...	...	0.00596	0.00363	0.00374	...	...

* Concentric lay stranded includes compressed and compact conductors.

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Table 2-3 (Metric)
NOMINAL DIRECT CURRENT RESISTANCE IN MILLIOHMS PER METER AT 25ºC
OF SOLID AND CONCENTRIC LAY STRANDED CONDUCTOR

Conductor Size AWG or kcmi	Solid			Concentric Lay Stranded*				
	Aluminum	Copper		Aluminum	Copper			
		Uncoated	Coated		Uncoated	Coated		
				Class A,B,C,D	Class B,C,D	Class B	Class C	Class D
8	3.44	2.10	2.16	3.51	2.14	2.22	2.22	2.23
7	2.73	1.67	1.71	2.79	1.70	1.76	1.76	1.76
6	2.17	1.32	1.36	2.21	1.35	1.40	1.40	1.40
5	1.72	1.05	1.08	1.75	1.07	1.11	1.11	1.11
4	1.36	0.830	0.856	1.39	0.846	0.882	0.882	0.882
3	1.08	0.659	0.679	1.10	0.672	0.699	0.699	0.699
2	0.856	0.522	0.538	0.872	0.531	0.554	0.554	0.554
1	0.679	0.413	0.426	0.692	0.423	0.440	0.440	0.440
1/0	0.538	0.328	0.335	0.551	0.335	0.348	0.348	0.348
2/0	0.426	0.260	0.267	0.436	0.266	0.276	0.276	0.276
3/0	0.338	0.207	0.212	0.344	0.211	0.219	0.219	0.219
4/0	0.269	0.164	0.168	0.274	0.167	0.172	0.174	0.174
250	0.228	...	...	0.232	0.141	0.147	0.147	0.147
300	0.190	...	...	0.194	0.118	0.123	0.123	0.123
350	0.162	...	...	0.166	0.101	0.105	0.105	0.105
400	0.142	...	...	0.145	0.0882	0.0909	0.0918	0.0918
450	0.126	...	...	0.129	0.0787	0.0807	0.0817	0.0817
500	0.114	...	...	0.116	0.0708	0.0728	0.0735	0.0735
550	...	...	...	0.105	0.0643	0.0669	0.0669	0.0669
600	...	...	...	0.0968	0.0590	0.0613	0.0613	0.0613
650	...	...	...	0.0892	0.0544	0.0561	0.0564	0.0567
700	...	...	...	0.0830	0.0505	0.0522	0.0525	0.0525
750	...	...	...	0.0774	0.0472	0.0485	0.0489	0.0492
800	...	...	...	0.0725	0.0443	0.0456	0.0459	0.0459
900	...	...	...	0.0643	0.0394	0.0403	0.0413	0.0413
1000	...	...	...	0.0581	0.0354	0.0364	0.0364	0.0367
1100	...	...	...	0.0528	0.0322	0.0331	0.0335	0.0335
1200	...	...	...	0.0482	0.0295	0.0303	0.0306	0.0306
1250	...	...	...	0.0462	0.0283	0.0291	0.0294	0.0294
1300	...	...	...	0.0446	0.0272	0.0280	0.0282	0.0283
1400	...	...	...	0.0413	0.0253	0.0260	0.0260	0.0263
1500	...	...	...	0.0387	0.0236	0.0243	0.0243	0.0245
1600	...	...	...	0.0364	0.0221	0.0228	0.0230	0.0230
1700	...	...	...	0.0341	0.0208	0.0214	0.0216	0.0216
1750	...	...	...	0.0331	0.0202	0.0208	0.0210	0.0210
1800	...	...	...	0.0322	0.0196	0.0202	0.0202	0.0204
1900	...	...	...	0.0305	0.0186	0.0192	0.0192	0.0193
2000	...	...	...	0.0290	0.0177	0.0182	0.0182	0.0184
2500	...	...	...	0.0235	0.0143	0.0147	...	...
3000	...	...	...	0.0195	0.0119	0.0123	...	...

* Concentric lay stranded includes compressed and compact conductors.

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Table 2-4
NOMINAL DIAMETERS FOR COPPER AND ALUMINUM CONDUCTORS

Conductor Size		Nominal Diameters (Inches)								
			Concentric Lay Stranded							
AWG	kcmil	Solid	Compact *	Compressed	Class A	Class B**	Class C	Class D	Combination Unilay	Unilay Compressed
8	16.51	0.1285	0.134	0.142	...	0.146	0.148	0.148	0.143	...
7	20.82	0.1443	...	0.159	...	0.164	0.166	0.166	0.160	...
6	26.24	0.1620	0.169	0.178	...	0.184	0.186	0.186	0.179	...
5	33.09	0.1819	...	0.200	...	0.206	0.208	0.208	0.202	...
4	41.74	0.2043	0.213	0.225	0.232	0.232	0.234	0.235	0.226	...
3	52.62	0.2294	0.238	0.252	0.260	0.260	0.263	0.264	0.254	...
2	66.36	0.2576	0.268	0.283	0.292	0.292	0.296	0.297	0.286	...
1	83.69	0.2893	0.299	0.322	0.328	0.332	0.333	0.333	0.321	0.313
1/0	105.6	0.3249	0.336	0.362	0.368	0.373	0.374	0.374	0.360	0.352
2/0	133.1	0.3648	0.376	0.405	0.414	0.419	0.420	0.420	0.404	0.395
3/0	167.8	0.4096	0.423	0.456	0.464	0.470	0.471	0.472	0.454	0.443
4/0	211.6	0.4600	0.475	0.512	0.522	0.528	0.529	0.530	0.510	0.498
	250	0.5000	0.520	0.558	0.574	0.575	0.576	0.576	0.554	0.542
	300	0.5477	0.570	0.611	0.629	0.630	0.631	0.631	0.607	0.594
	350	0.5916	0.616	0.661	0.679	0.681	0.681	0.682	0.656	0.641
	400	0.6325	0.659	0.706	0.726	0.728	0.729	0.729	0.701	0.685
	450	0.6708	0.700	0.749	0.772	0.772	0.773	0.773	0.744	0.727
	500	0.7071	0.736	0.789	0.813	0.813	0.814	0.815	0.784	0.766
	550	...	0.775	0.829	0.853	0.855	0.855	0.855	...	0.804
	600	...	0.813	0.866	0.891	0.893	0.893	0.893	...	0.840
	650	...	0.845	0.901	0.929	0.929	0.930	0.930	...	0.874
	700	...	0.877	0.935	0.964	0.964	0.965	0.965	...	0.907
	750	...	0.908	0.968	0.998	0.998	0.999	0.998	...	0.939
	800	...	0.938	1.000	1.031	1.031	1.032	1.032	...	0.969
	900	...	0.999	1.060	1.094	1.094	1.093	1.095	...	1.028
	1000	...	1.060	1.117	1.152	1.152	1.153	1.153	...	1.084
	1100	...	...	1.173	1.209	1.209	1.210	1.211	...	1.137
	1200	...	...	1.225	1.263	1.263	1.264	1.264	...	1.187
	1250	...	...	1.250	1.288	1.289	1.290	1.290	...	1.212
	1300	...	...	1.275	1.314	1.315	1.316	1.316	...	1.236
	1400	...	...	1.323	1.364	1.364	1.365	1.365	...	1.282
	1500	...	...	1.370	1.411	1.412	1.413	1.413	...	1.327
	1600	...	...	1.415	1.459	1.459	1.460	1.460	...	1.371
	1700	...	...	1.459	1.504	1.504	1.504	1.504	...	1.413
	1750	...	...	1.480	1.526	1.526	1.527	1.527	...	1.434
	1800	...	...	1.502	1.547	1.548	1.548	1.549	...	1.454
	1900	...	...	1.542	1.590	1.590	1.590	1.591	...	1.494
	2000	...	...	1.583	1.630	1.632	1.632	1.632	...	1.533
	2500	...	...	1.769	1.823	1.824	1.824	1.824	...	...
	3000	...	...	1.938	1.998	1.998	1.999	1.999	...	...

* Diameters shown are for compact round, compact modified concentric and compact single input wire.

** Diameters shown are for concentric round and modified concentric.

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Table 2-4 (Metric)
NOMINAL DIAMETERS FOR COPPER AND ALUMINUM CONDUCTORS

Conductor Size		Nominal Diameters (mm)								
AWG			Concentric Lay Stranded							
or kcmil	mm^2	Solid	Compact *	Compressed	Class A	Class B**	Class C	Class D	Combination Unilay	Unilay Compressed
8	8.37	3.26	3.40	3.58	...	3.71	3.76	3.76	3.63	...
7	10.6	3.67	...	4.01	...	4.17	4.22	4.22	4.06	...
6	13.3	4.11	4.29	4.52	...	4.67	4.72	4.72	4.55	...
5	16.8	4.62	...	5.08	...	5.23	5.28	5.31	5.13	...
4	21.1	5.19	5.41	5.72	5.89	5.89	5.94	5.97	5.74	...
3	26.7	5.83	6.05	6.40	6.60	6.60	6.68	6.71	6.45	...
2	33.6	6.54	6.81	7.19	7.42	7.42	7.52	7.54	7.26	...
1	42.4	7.35	7.59	8.18	8.33	8.43	8.46	8.46	8.15	7.95
1/0	53.5	8.25	8.53	9.19	9.35	9.47	9.50	9.50	9.14	8.94
2/0	67.4	9.27	9.55	10.3	10.5	10.6	10.7	10.7	10.3	10.0
3/0	85.0	10.4	10.7	11.6	11.8	11.9	12.0	12.0	11.5	11.3
4/0	107	11.7	12.1	13.0	13.3	13.4	13.4	13.5	13.0	12.6
250	127	12.7	13.2	14.2	14.6	14.6	14.6	14.6	14.1	13.8
300	152	13.9	14.5	15.5	16.0	16.0	16.0	16.0	15.4	15.1
350	177	15.0	15.6	16.8	17.2	17.3	17.3	17.3	16.7	16.3
400	203	16.1	16.7	17.9	18.4	18.5	18.5	18.5	17.8	17.4
450	228	17.0	17.8	19.0	19.6	19.6	19.6	19.6	18.9	18.5
500	253	18.0	18.7	20.0	20.7	20.7	20.7	20.7	19.9	19.5
550	279	...	19.7	21.1	21.7	21.7	21.7	21.7	...	20.4
600	304	...	20.7	22.0	22.6	22.7	22.7	22.7	...	21.3
650	329	...	21.5	22.9	23.6	23.6	23.6	23.6	...	22.2
700	355	...	22.3	23.7	24.5	24.5	24.5	24.5	...	23.0
750	380	...	23.1	24.6	25.3	25.3	25.4	25.3	...	23.9
800	405	...	23.8	25.4	26.2	26.2	26.2	26.2	...	24.6
900	456	...	25.4	26.9	27.8	27.8	27.8	27.8	...	26.1
1000	507	...	26.9	28.4	29.3	29.3	29.3	29.3	...	27.5
1100	557	...	...	29.8	30.7	30.7	30.7	30.8	...	28.9
1200	608	...	...	31.1	32.1	32.1	32.1	32.1	...	30.1
1250	633	...	...	31.8	32.7	32.7	32.8	32.8	...	30.8
1300	659	...	...	32.4	33.4	33.4	33.4	33.4	...	31.4
1400	709	...	...	33.6	34.6	34.6	34.7	34.7	...	32.6
1500	760	...	...	34.8	35.8	35.9	35.8	35.9	...	33.7
1600	811	...	...	35.9	37.1	37.1	37.1	37.1	...	34.8
1700	861	...	...	37.1	38.2	38.2	38.2	38.2	...	35.9
1750	887	...	...	37.6	38.8	38.8	38.8	38.8	...	36.4
1800	912	...	...	38.2	39.3	39.3	39.3	39.3	...	36.9
1900	963	...	...	39.2	40.4	40.4	40.4	40.4	...	37.9
2000	1013	...	...	40.2	41.4	41.5	41.5	41.5	...	38.9
2500	1266	...	...	44.9	46.3	46.3	46.3	46.3	...	...
3000	1520	...	...	49.2	50.7	50.7	50.8	50.8	...	...

* Diameters shown are for compact round, compact modified concentric and compact single input wire.

** Diameters shown are for concentric round and modified concentric.

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Table 2-5*
† FACTORS FOR DETERMINING NOMINAL RESISTANCE OF STRANDED CONDUCTORS PER 1000 FEET AT 25°C

Conductor Size	All Sizes		Diameter of Individual Tin Coated Copper Wires in Inches for Stranded Conductors				
	Aluminum	Uncoated copper	0.460 to 0.290, Inclusive	Under 0.290 to 0.103, Inclusive	Under 0.103 to 0.0201, Inclusive	Under 0.0201 to 0.0111, Inclusive	Under 0.0111 to 0.0010, Inclusive
Concentric Stranded 8 AWG - 2000 kcmil	17692	10786	11045	11102	11217	11456	11580
> 2000 - 3000 kcmil	17865	10892	11153	11211	11327	11568	11694
Conductivity utilized for above factors, Percent	61	100	97.66	97.16	96.16	94.16	93.15

* The factors given in Table 2-5 shall be based on the following:

A. Resistivity
   1. A volume resistivity of 10.575 Ω•cmil/ft (100% conductivity) at 25°C for uncoated (bare) copper.
   2. A 25°C volume resistivity converted from the 20°C values specified in ASTM B 33 for tin coated copper.
   3. A volume resistivity of 17.345 Ω•cmil/ft (61.0% conductivity) at 25°C for aluminum.

B. Increase in Resistance Due to Stranding
   1. The value of K (weight increment factor) given in Table 2-1.

† See Table 2-2 for Use of Factors.

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Section 3
CONDUCTOR SHIELD (STRESS CONTROL LAYER)

3.1 MATERIAL

The conductor shall be covered with an extruded thermosetting conductor shield material. The stress control layer shall be a polymeric covering consisting of an extruded material or extruded material over a conducting tape. The layer shall have a minimum thickness of 0.006" inches (0.15mm). Minimum tape thickness shall be 0.0025" (0.06mm).

The extruded material shall be either semiconducting or nonconducting for ethylene propylene rubber (EPR) type insulation and semiconducting only for crosslinked polyethylene (XLPE or TRXLPE) type insulation. The allowable operating temperatures of the conductor shield shall be equal to or greater than those of the insulation. The conductor shield shall be easily removable from the conductor and the outer surface of the extruded shield shall be firmly bonded to the overlying insulation.

For 5 kV rated cables, the conductor shield may consist of a semiconducting tape.

3.2 PHYSICAL REQUIREMENTS

The crosslinked material intended for extrusion as a conductor shield shall meet the following requirements:

Physical Requirements	Extruded Conductor Shield
Elongation after air oven test for 168 hours at 121°C ± 1°C (for insulations rated 90°C) or at 136°C ± 1°C (for insulations rated 105°C), minimum percent	100
Brittleness temperature not warmer than, °C	-10

3.3 ELECTRICAL REQUIREMENTS

3.3.1 Extruded Semiconducting Material

(See 9.13.) The volume resistivity of the extruded semiconducting conductor shield shall not exceed 1000 ohm-meter at the maximum normal operating temperature and emergency operating temperature.

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3.3.2 Extruded Nonconducting Material (For EPR Insulation Only)

The extruded nonconducting conductor shield shall withstand a 2.0 kV dc spark test, Table 9-1 of Section 9, and meet the following requirements at room temperature and at the maximum normal and emergency operating temperature:

Dielectric Constant (SIC), range 8 – 200

60 Hz ac voltage withstand

Stress, Volts per mil, min: $\frac{1500}{\text{Dielectric Constant}}$

Stress, kV per mm, min: $\frac{59}{\text{Dielectric Constant}}$

3.3.3 Semiconducting Tape

If a semiconducting tape is used over the conductor, the maximum dc resistance of the tape at room temperature shall be 10,000 ohms per unit square when determined in accordance with ASTM D 4496.

3.4 WAFER BOIL TEST

(See 9.19.) The extruded conductor shield shall be effectively crosslinked.

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Section 4
INSULATION

4.1 MATERIAL

The insulation shall be one of the following materials meeting the dimensional, electrical, and physical requirements specified in this section:

- Filled or unfilled crosslinked polyethylene (XLPE)
- Filled or unfilled tree retardant crosslinked polyethylene (TRXLPE)
- Ethylene propylene rubber (EPR)

A filled crosslinked polyethylene insulation (XLPE or TRXLPE), meeting the requirements of this specification, is one that contains 10 percent or more of mineral fillers by weight. A tree retardant crosslinked polyethylene insulation is a compound containing; an additive, a polymer modification, or filler which provides treeing retardance to the compound. These XLPE and TRXLPE insulations are intended for use only in cables of the "DISCHARGE-FREE" design concept. (See 4.3.1)

Ethylene propylene rubber insulation has four classifications:

I, II & III are for use only in cables of the "DISCHARGE-FREE" design (See 4.3.1.)
IV is for use only in cables of the "DISCHARGE-RESISTANT" design (See 4.3.2.)

All of the insulations are suitable for use on cables in wet or dry locations at voltages between 5 and 46 kV between phases at the 100 and 133 percent insulation level. The conductor temperature shall not exceed the following:

Insulation Material	Normal Operation	Emergency Overload *	Short Circuit***
XLPE, TRXLPE, and EPR Classes I, II & IV	90 °C	130 °C	250 °C
EPR Class III	105 °C**	140 °C	250 °C

* See Appendix B

** Lower temperatures for normal operation may be required because of the type of material used in the cable joints and terminations or because of cable environmental conditions. Cable users should be aware that all of the jackets described in Section 7 are not necessarily suitable for cables having this maximum temperature rating. Consult cable manufacturer for further information.

*** Conductor fault current shall be determined in accordance with ICEA P-32-382.

4.2 INSULATION THICKNESS

The insulation thicknesses given in Table 4-1 are based on the rated circuit voltage, phase-to-phase, and on the cable insulation level.

The minimum thickness and maximum thickness of the insulation shall be as specified in Table 4-1. (See 9.2.2 for method of measurement.)

For identification, nominal thicknesses are shown in Section 8 Table 8-2.

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4.2.1 Selection of Proper Thickness

The thickness of insulation for various systems shall be determined as follows:

4.2.1.1 For Three-Phase Systems with 100 or 133 Percent Insulation Level

Use the thickness values given in the respective columns of Table 4-1.

4.2.1.2 For Delta Systems Where One Phase May Be Grounded For Periods Over One Hour

See 173 percent level in note following Table 4-1.

4.2.1.3 For Single- and Two-Phase Systems with 100 Percent Insulation Level

Multiply the voltage to ground by 1.73 and use the resulting voltage value or next higher rating to select the corresponding insulation thickness in the 100 percent insulation level column of Table 4-1.

4.2.1.4 For Single- and Two-Phase Systems with 133 Percent Insulation Level

Multiply the voltage to ground by 1.73 and use the resulting voltage value or next higher rating to select the corresponding insulation thickness in the 133 percent insulation level column of Table 4-1.

4.3 INSULATION REQUIREMENTS

Insulations used in DISCHARGE-FREE cable designs are described in 4.3.1.

Discharge-Free Cable Design: A cable designed to eliminate electrical discharge in the insulation at normal operating voltage.

Insulations used in DISCHARGE-RESISTANT cable designs are described in 4.3.2.

Discharge-Resistant Cable Design: A cable design capable of withstanding electrical discharge.

4.3.1 Insulation for DISCHARGE-FREE Cable Designs Only

4.3.1.1 Physical and Aging Requirements

When tested in accordance with Section 9, the insulation shall meet the following requirements:

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Physical Requirements	Insulation Type				
	XLPE and TRXLPE		EPR Class		
	Unfilled	Filled	I	II	III
Unaged Requirements					
Tensile Strength, Minimum psi (MPa)	1800 (12.5)		700 (4.8)	1200 (8.2)	700 (4.8)
Elongation at Rupture, Minimum Percent	250		250		
Aging Requirements After Air Oven Aging for 168 hours					
Aging Temperature, °C	121		121		136
Tensile Strength, Minimum Percentage of Unaged Value	75		75	80	75
Elongation, Minimum Percentage of Unaged Value	75		75	80	75
Hot Creep Test at 150°C ± 2 °C					
*Elongation, Maximum Percent	175	100	50		
*Set, Maximum Percent	10	5	5		

*For XLPE and TRXLPE insulations if this value is exceeded, the Solvent Extraction Test may be performed and will serve as a referee method to determine compliance (a maximum of 30 percent weight loss after 20 hour drying time).

4.3.1.2 Electrical Requirements

4.3.1.2.1 Partial-Discharge Extinction Level

(See 9.12.2.) Each length of completed cable shall be subjected to a partial discharge test. For cables shielded with a nonmetallic semiconducting layer extruded directly over the insulation , the partial discharge shall not exceed 5 picocoulombs at the ac test voltage given in Table 4-1 or 4-1 (Metric). For cables shielded with a semiconducting coating and a semiconducting tape, the partial discharge shall not exceed 5 picocoulombs at the ac test voltage given in the following:

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PARTIAL DISCHARGE REQUIREMENTS FOR SEMICONDUCTING COATING AND TAPE DESIGNS ONLY

Rated Circuit Voltage, Phase to Phase, Volts	Minimum Partial Discharge Extinction Level, kV	
	100 % Insulation Level	133% Insulation Level
2001-5000	4	5*
5001-8000	6	8
8001-15000	11	15

* Unless otherwise indicated, the cable will be rated at the 100% insulation level.

4.3.1.2.2 Voltage Tests

(See 9.12.1.) Each length of completed cable shall withstand, without failure, the ac test voltages given in Table 4-1. The test voltage shall be based on the rated voltage of the cable and the size of the conductor.

Factory dc testing is not required by this specification. However, a dc test may be performed with prior agreement between the manufacturer and the purchaser. Suggested dc test voltages are listed in Appendix D.

4.3.1.2.3 Insulation Resistance

(See T-27-581.) Each insulated conductor in the completed cable shall have an insulation resistance not less than that corresponding to a constant of 20,000 at 15.6 °C.

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4.3.1.2.4 Accelerated Water Absorption

(See T-27-581.) The insulation shall meet the following requirements:

Accelerated Water Absorption Properties (Electrical Method)	Insulation Type		
	XLPE and TRXLPE	EPR Class I & II	EPR Class III
Water Immersion Temperature, °C	75	75	90
Dielectric Constant after 24 hours, maximum	3.5	4.0	
Increase in capacitance, maximum, percent 1 to 14 days 7 to 14 days	 3.0 1.5	 3.5 1.5	
Stability Factor after 14 days, maximum*	1.0		
Alternate to Stability Factor (Stability Factor difference, 1 to 14 days) maximum*	0.5		

*Only one of these two requirements need be satisfied, not both.

4.3.1.2.5 Dielectric Constant and Dissipation Factor

(See T-27-581.) The insulation shall meet the following maximum requirements for dielectric constant and dissipation factor at room temperature.

Properties	Insulation Type		
	XLPE	TRXLPE	EPR Class I, II & III
Dielectric Constant	3.5	3.5	4.0
Dissipation Factor, Percent	0.1	0.5	1.5

4.3.1.2.6 Dry Electrical Test For EPR Class III Insulation Only

(See 9.21.) A completed cable core with this insulation shall meet the following requirements.

a. Demonstrate a partial discharge level not greater than 5 picocoulombs at 150 volts per mil (5.9 kV/mm) ac electrical stress before and after testing.

b. Demonstrate no more than a 10 percent increase in dissipation factor (tan δ) after testing.

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4.3.2 Insulation For DISCHARGE-RESISTANT Cable Designs Only

4.3.2.1 Physical and Aging Requirements

When tested in accordance with Section 9, the insulation shall meet the following requirements:

Physical Requirements	EPR Class IV All Voltage Ratings
Unaged Requirements	
Tensile Strength, Minimum Psi (MPa)	 550 (3.8)
Elongation at Rupture, Minimum Percent	250
Aging Requirements After Air Oven Aging at 121°C ± 1°C for 168 hours	
Tensile Strength, Minimum Percentage of Unaged Value	75
Elongation at Rupture, Minimum Percent	175
Hot Creep Test at 150°C ± 2°C	
Elongation, Maximum Percent	50
Set, Maximum Percent	5

4.3.2.2 Electrical Requirements

4.3.2.2.1 Discharge (Corona)

(See 9.16.) The insulation shall be verified as corona discharge resistant using a 21 kV 60 Hz voltage applied for 250 hours. No failure nor surface erosion visible with 15 times magnification shall occur. Partial discharge measurements are not required for DISCHARGE-RESISTANT cables.

4.3.2.2.2 Voltage Tests

(See 9.12.1.) Each length of completed cable shall withstand, without failure, the ac test voltages given in Table 4-1. The test voltage shall be based on the rated voltage of the cable and the size of the conductor.

Factory dc testing is not required by this specification. However, a dc test may be performed with prior agreement between the manufacturer and the purchaser. Suggested dc test voltages are listed in Appendix F.

4.3.2.2.3 Insulation Resistance

(See T-27-581.) Each insulated conductor in the completed cable shall have an insulation resistance not less than that corresponding to a constant of 20,000 at 15.6 °C.

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4.3.2.2.4 Accelerated Water Absorption

(See T-27-581.) The insulation shall meet the following requirements:

Accelerated Water Absorption Properties (Electrical Method at 75 °C)	EPR Class IV	
	For Cables Rated 28 kV or less	For Cables Rated 35 kV and 46 kV
Dielectric Constant after 24 hours, maximum	4.0	4.0
Increase in capacitance, maximum percent 1 to 14 days 7 to 14 days	 7.0 4.0	 3.5 1.5
Stability Factor after 14 days, maximum*	1.0	1.0
Alternate to Stability Factor (Stability Factor difference, 1 to 14 days) maximum*	0.5	0.5

***** Only one of these two requirements need to be satisfied, not both.

4.3.2.2.5 Dielectric Constant and Dissipation Factor

(See T-27-581.) The insulation shall meet the following maximum requirements for dielectric constant and dissipation factor at room temperature.

Properties	EPR Class IV	
	Cables Rated 5-28 kV	For Cables Rated 35 kV & 46 kV
Dielectric Constant	4.0	4.0
Dissipation Factor, Percent	2.0	1.5

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Table 4-1
CONDUCTOR SIZES, INSULATION THICKNESSES AND TEST VOLTAGES

Rated Circuit Voltage, Phase-to-Phase Voltage[a]	Conductor Size, (AWG or kcmil)[b]	Insulation Level[c] (mils)				a-c Test Voltage, kV[d]	
		100 Percent		133 Percent		100 Percent Insulation Level	133 Percent Insulation Level
		Minimum	Maximum	Minimum	Maximum		
2001-5000	8-1000[e]	85	120	85	120	18	18
	1001-3000	135	170	135	170	28	28
5001-8000	6-1000	110	145	135	170	23	28
	1001-3000	165	205	165	205	35	35
8001-15000	2-1000	165	205	210	250	35	44
	1001-3000	210	250	210	250	44	44
15001-25000	1-3000	245	290	305	350	52	64
25001-28000	1-3000	265	310	330	375	56	69
28001-35000	1/0-3000	330	375	400	450	69	84
35001-46000	4/0-3000	425	485	550	610	89	116

Table 4-1 (Metric)
CONDUCTOR SIZES, INSULATION THICKNESSES AND TEST VOLTAGES

Rated Circuit Voltage, Phase-to-Phase Voltage[a]	Conductor Size, (mm^2)[b]	Insulation Level[c] (mm)				a-c Test Voltage, kV[d]	
		100 Percent		133 Percent		100 Percent Insulation Level	133 Percent Insulation Level
		Minimum	Maximum	Minimum	Maximum		
2001-5000	8.37-506.7[e]	2.16	3.05	2.16	3.05	18	18
	506.8-1520	3.43	4.32	3.43	4.32	28	28
5001-8000	13.3-506.7	2.79	3.68	3.43	4.32	23	28
	506.8-1520	4.19	5.21	4.19	5.21	35	35
8001-15000	33.6-506.7	4.19	5.21	5.33	6.35	35	44
	506.8-1520	5.33	6.35	5.33	6.35	44	44
15001-25000	42.4-1520	6.22	7.37	7.75	8.89	52	64
25001-28000	42.4-1520	6.73	7.87	8.38	9.53	56	69
28001-35000	53.5-1520	8.38	9.53	10.2	11.4	69	84
35001-46000	107.2-1520	10.8	12.3	14.0	15.5	89	116

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Notes on Table 4-1 & 4-1 (Metric):

[a]The actual operating voltage shall not exceed the rated circuit voltage by more than (a) 5 percent during continuous operation or (b) 10 percent during emergencies lasting not more than 15 minutes.

[b]To limit the maximum voltage stress on the insulation at the conductor to a safe value, the conductor size shall not be less than the minimum size shown for each rated circuit voltage category.

[c]Selection of the cable insulation level to be used in a particular installation shall be made on the basis of the applicable phase-to-phase voltage and the general system category as outlined below:

100 Percent Level - Cables in this category may be applied where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible, but in any case within 1 minute. While these cables are applicable to the great majority of cable installations that are on grounded systems, they may be used also on other systems for which the application of cable is acceptable provided the above clearing requirements are met in completely de-energizing the faulting section.

Where additional insulation thickness is desired, it shall be the same as for the 133 percent insulation level.

133 Percent Level - This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category may be applied in situations where the clearing time requirements of the 100 percent level category cannot be met, and yet there is adequate assurance that the faulted section will be de-energized in a time not exceeding 1 hour. Also they may be used when additional insulation strength over the 100 percent level category is desirable.

173 Percent Level - Cables in this category should be applied on systems where the time required to de-energize a grounded section is indefinite. Their use is recommended also for resonant grounded systems. Consult the manufacturer for insulation thicknesses.

[d]All a-c voltages are rms values.

[e]There may be unusual installations and/or operating conditions where mechanical considerations dictate the use of the 133% thicker insulation (such as a 110 mil minimum {8 kV 100%} on some of these conductor sizes. When such conditions are anticipated, the user should consult with the cable supplier to determine the appropriate insulation thickness.

In common with other electrical equipment, the use of cables is not recommended on systems where the ratio of the zero to positive phase sequence reactance of the system at the point of cable application lies between -1 and -40 since excessively high voltages may be encountered in the case of ground faults.

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Section 5
INSULATION SHIELDING

5.1 SHIELDING OF INSULATED CABLE

Shielding of insulated cables shall consist of conductor stress control layer and insulation shielding. For stress control layer see Section 3.

5.1.1 Insulation Shield

The insulation shield system shall consist of a non-metallic covering directly over the insulation and a non-magnetic metal component directly over or embedded in the nonmetallic covering. The nonmetallic covering shall comply with 5.1.1.1. The metal component shall comply with Section 6. The insulation shield system shall be resistant to or protected against chemical action from other cable components.

5.1.1.1 Nonmetallic Covering

A semiconducting nonmetallic covering that meets the requirements of Table 5-1 or 5-2 shall be applied in one or more layers in direct contact with the insulation and shall be plainly identified as being conducting. Identification shall be provided for each distinctive layer.

For cables rated up to and including 15kV, the nonmetallic covering may consist of a semiconducting coating and a semiconducting tape. A marker tape, placed directly under the metallic shielding, shall be printed with the legend "Remove the underlying semiconducting tape and coating before splicing and terminating." The semiconducting tape shall consist of nylon cloth coated, impregnated, frictioned or calendared on one face and skimmed on the other face with a rubber compound. The skim coat may be cured or uncured and shall contain no sulphur or other ingredients which will react with the metals contacting the tape. The nominal thickness of the tape shall be 5 mils or greater. The semiconducting tape shall be helically applied to the cable with printed side up with 10% or more overlap on itself. The tape shall be free of significant creases or wrinkles.

5.2 REMOVABILITY OF INSULATION SHIELD

The insulation shield shall be removable without damaging or imparting conductivity to the underlying insulation**.** See Appendix G, G6.1.

5.2.1 Discharge-Free Cable Designs With Extruded Insulation Shields

(See 9.14.) The tension necessary to remove an extruded insulation shield from the insulation at room temperature shall be not less than 3 pounds (13.4 N) and not greater than 24 pounds (107 N). The insulation shield shall be readily removable in the field at temperatures from -10°C to 40°C when scored to a depth of 1 mil less than the specified minimum point thickness of the insulation shield.

At the option/approval of the purchaser, an extruded insulation shield which is bonded may be supplied. In this case, the tension necessary to remove the insulation shield at room temperature shall be not less than 24 pounds (107 N).

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5.2.2 Discharge-Resistant Cable Designs With Extruded Insulation Shields

There is no minimum tension requirement for removing an extruded insulation shield used with a discharge-resistant cable.

Table 5-1
REQUIREMENTS FOR NONMETALLIC CONDUCTING COVERINGS USING NONEMBEDDED METAL COMPONENTS

	Thermo-plastic	Cross-Linked Rated 90°C	Cross-Linked Rated 105°C
Aging Requirements (see Section 9)			
After air oven test at 100°C ± 1°C for 48 hrs.			
Elongation at rupture, min. percent	100*	---	---
After air oven test at 121°C ± 1°C for 168 hrs.			
Elongation at rupture, min. percent	---	100*	---
After air oven test at 136°C ± 1°C for 168 hrs.			
Elongation at rupture, min. percent	---	---	100*
Brittleness Temperature, not warmer than	-25°C*	-25°C*	-25°C*
Volume Resistivity, maximum at rated temperature ± 1°C and 110°C, ohm-meters	500	500	500

*For extruded coverings only.

Table 5-2
REQUIREMENTS FOR EXTRUDED NONMETALLIC CONDUCTING COVERINGS USING EMBEDDED METAL COMPONENTS

Thickness, Minimum (see Section 9)	
Total	Per Table 7-3
Between insulation and metal component, mils (mm)	5 (0.127)
Physical Requirements	
Tensile strength, minimum	
psi	1200
Mpa	8.27
Elongation at rupture, minimum, percent	100
Aging Requirements - after air oven test for 168 hours at 121°C ± 1°C for insulations rated 90°C or at 136°C ± 1°C for insulations rated 105°C	
Tensile strength, minimum, percentage of unaged value	85
Elongation at rupture, minimum, percent	100
Brittleness Temperature, not warmer than	-10°C
Volume Resistivity, maximum at rated temperature ± 1°C and 110°C ± 1°C, ohm-meters	500

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Section 6
METALLIC SHIELDING (SEE APPENDIX G)

6.1 GENERAL

A nonmagnetic metal shield consisting of a tape or tapes, wires, straps, sheath or armor shall be applied over or embedded in the semiconducting nonmetallic covering. The metal shield shall be electrically continuous throughout each cable length and shall be in contact with the insulation shield. The metal shield shall be applied in such a manner that electrical continuity or contiguity will not be distorted or disrupted during normal installation bending. (See Appendix I.)

Metal tapes, wires, straps, sheath or armor may be used in combination providing they are compatible and meet the requirements of the following paragraphs.

Metal components embedded in a conducting nonmetallic covering shall not be exposed nor become exposed during normal installation bending. (See Appendix I.)

6.2 METAL TAPES (SEE ICEA T-27-581/NEMA WC-53)

Metal tape(s) shall be copper at least 0.0025 inches (0.0635 mm) thick or of other nonmagnetic metal tape(s) having equivalent conductance.

6.2.1 Helically Applied Tape(s)

A tin coated or uncoated copper tape shall be applied helically in intimate contact with the underlying semiconducting layer. The tape(s) shall be free from burrs. Joints in the tape(s) shall be made electrically continuous by welding, soldering, or brazing. Butted tapes shall not be permitted. Tape(s) shall be lapped by at least 10% of the tape width or may be gapped by a maximum of 20% and a minimum of 5% of the tape width. The direction of lay may be right-hand or left-hand.

6.2.2 Longitudinally Applied Corrugated Tape

A longitudinally applied corrugated tape shield shall be annealed copper. Joints in the tape shall be made electrically continuous by welding, soldering, or brazing. The width of the corrugated tape shield shall be such that after corrugation the edges shall overlap by not less than 0.250 inches (6.35 mm) when the tape is longitudinally formed over the insulated core. The corrugation shall be at right angles to the axis of the cable, shall coincide exactly at the overlap, and shall be in contact with the underlying semiconducting layer.

6.3 COPPER WIRES, STRAPS, SHEATH OR ARMOR

Copper wires, straps, sheath or armor shall have a total area at any cross section of at least 5000 circular mils per inch ($0.1mm^2/mm$) of insulated core diameter as determined by Equation 1 given in Appendix C. The minimum wire size shall be #25 AWG. The minimum number of wires shall be six. Other nonmagnetic metals having equivalent conductance may be used.

Helically applied wire shield shall have a lay length of not less than four times nor greater than ten times the calculated diameter based on Equation 1, Appendix C. The direction of lay may be either left or right. Corrugated wires embedded in a semiconducting non-metallic covering may be applied parallel to the axis of the conductor.

NOTE - Additional conductance may be required in the metal shield depending upon installation and electrical system characteristics, particularly in regard to the functioning of overcurrent protective devices, available fault current, and the manner in which the system may be grounded. ICEA Publication P-45-482 may be utilized to determine metallic shield fault-clearing capability.

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6.4 MULTIPLE-CONDUCTOR CABLES

The shield shall be applied over each individual conductor in a multiple-conductor cable.

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Section 7
COVERINGS

7.1 JACKETS

7.1.1 Cross-linked and Thermoplastic Jackets - General

The jackets described in 7.1.2 through 7.1.15 may be applied with or without a separator directly over the metallic shielding or over an assembly of shielded insulated conductors. The jacket shall meet the requirements stated therein and those given in Table 7-1. Jacket thickness shall be in accordance with 7.1.20.

Jackets for application over metallic coverings are listed in 7.3.8 and 7.3.9. The jacket shall meet the requirements stated therein and in Table 7-1.

In classifying jackets and sheaths in these standards, the term "jacket" refers to nonmetallic coverings and "sheath" refers to continuous metallic coverings.

7.1.2 Neoprene, Heavy-Duty Black

(CR-HD)

This jacket shall consist of a cross-linked black neoprene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.3 Neoprene, General Purpose

(CR-GP)

This jacket shall consist of a cross-linked neoprene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.4 Polyvinyl Chloride

(PVC)

This jacket shall consist of a polyvinyl chloride compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.5 Low and Linear Low Density Polyethylene

(LDPE & LLDPE)

This jacket shall consist of a black, low density or linear low density polyethylene compound suitable for exposure to sunlight. When tested in accordance with Section 9 the jacket shall meet the applicable requirements of Table 7-1.

7.1.6 Medium Density Polyethylene, Black

(MDPE)

This jacket shall consist of a black, medium density polyethylene compound suitable for exposure to sunlight. When tested in accordance with Section 9 the jacket shall meet the applicable requirements of Table 7-1.

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7.1.7 High Density Polyethylene

(HDPE)

This jacket shall consist of a black, high density polyethylene compound suitable for exposure to sunlight and shall be used only as a covering over a metallic shield, sheath, or armor. When tested in accordance with Section 9 (except that the gauge marks shall be 1 inch (25.4 mm) apart and the distance between jaws 2.5 inches (63.5 mm)) the jacket shall meet the applicable requirements of Table 7-1.

7.1.8 Nitrile-butadiene/Polyvinyl-chloride, Heavy-Duty

(NBR/PVC-HD)

This jacket shall consist of a cross-linked acrylonitrile-butadiene/polyvinyl-chloride compound suitable for exposure to sunlight. It shall be based on a fluxed blend of acrylonitrile-butadiene synthetic rubber and polyvinyl-chloride resin. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.9 Nitrile-butadiene/Polyvinyl-chloride, General —Purpose Duty

(NBR/PVC-GP)

This jacket shall consist of a cross-linked acrylonitrile-butadiene/polyvinylchloride compound suitable for exposure to sunlight. It shall be based on a fluxed blend of acrylonitrile-butadiene synthetic rubber and polyvinyl-chloride resin. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.10 Chlorosulfonated Polyethylene, Heavy Duty

(CSPE-HD)

This jacket shall consist of a cross-linked chlorosulfonated-polyethylene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.11 Chlorinated Polyethylene, Thermoplastic

(CPE-TP)

This jacket shall consist of a thermoplastic chlorinated polyethylene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.12 Chlorinated Polyethylene, Cross-Linked, Heavy Duty

(CPE-XL-HD)

This jacket shall consist of a cross-linked chlorinated polyethylene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements of Table 7-1.

7.1.13 Polypropylene

(PP)

This jacket shall consist of a black thermoplastic polypropylene compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the requirements of Table 7-1.

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7.1.14 Thermoplastic Elastomer

(TPE)

This jacket shall consist of a black heavy duty thermoplastic elastomer (TPE) compound suitable for exposure to sunlight. When tested in accordance with Section 9 the jacket shall meet the requirements of Table 7-1.

7.1.15 Low Smoke Halogen Free Jackets

This jacket shall consist of either a thermoplastic or thermoset low smoke, halogen free compound suitable for exposure to sunlight. When tested in accordance with Section 9, the jacket shall meet the applicable requirements specified in Table 7-2.

7.1.16 Repairs

The jacket may be repaired in accordance with good commercial practice. Cables with repaired jackets must be capable of meeting all applicable requirements of this standard.

7.1.17 Test for Suitability for Exposure to Sunlight

Jackets intended for direct exposure to sunlight shall be qualified for such use. Tests shall be performed in accordance with either ASTM G23 or G26. A jacket is considered sunlight resistant if after 720 hours exposure the tensile and elongation properties retain a minimum of 80% of their original values.

7.1.18 Optional Tray Cable Flame Test Requirement

The following requirement is optional and shall not be required unless specified.

This test shall be performed in accordance with ICEA T-30-520. Cable shall not propagate flame to the top of the test specimens.

7.1.19 Separator Under Jacket

If a separator is used over a metallic shield or an assembly of conductors prior to jacketing, it shall consist of compatible material.

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Table 7-1
JACKET REQUIREMENTS

Properties	CR HD	CR GP	PVC	LDPE& LLDPE	MD PE	HD PE	NBR/PVC HD	NBR/PVC GP	CSPE HD	CPE TP	CPE-XL HD	PP	TPE
Unaged tensile strength at rupture, minimum													
psi	1800	1500	1500	1700	2300	2500	1800	1500	1800	1400	1800	2500	1800
MPa	12.4	10.3	10.3	11.7	15.9	17.2	12.4	10.3	12.4	9.65	12.4	17.2	12.4
Unaged elongation at rupture, minimum %	300	250	100	350	350	350	300	250	300	150	300	350	350
Unaged Tensile stress at elongation %,	200						200		200	100	200		200
minimum, psi	500						500		500	1000	500		400
MPa	3.45						3.45		3.45	6.89	3.45		2.76
Unaged Set, maximum %	20	20					30	30	30				
Retention, minimum percentage of unaged													
tensile strength	50	50	85	75	75	75	50	50	85	85	85	75	75
elongation	50	50	60	75	75	75	50	50	65	50	65	75	75
After air oven exposure at °C	100	100	100	100	100	100	100	100	100	121	100	121	121
for hours duration	168	168	120	48	48	48	168	168	168	168	168	168	168
Retention, minimum percentage of unaged													
tensile strength	60	60	80				60	60	60	60	60		75
elongation	60	60	60				60	60	60	60	60		75
After oil immersion test at °C	121	121	70				121	121	121	100	121		70
for hours duration	18	18	4				18	18	18	18	18		4
Heat Distortion at °C			121	100	110	110				121		136	121
maximum %			50	30	30	30				25		15	25
Heat shock at 121°C ±1°C, cracks allowed			No										
Environmental stress cracking, cracks allowed				No†	No††	No††						No††	
Cold Bend at -35°C ±1°C, cracks allowed			No							No			
Absorption Coefficient, minimum ‡ milli (absorbance/meter)				320	320	320						320	
Base Resin Density (D^{23C}), g/cm^3 ‡ min				0.910	0.926	0.941							
max				0.925	0.940	0.965							
Hot Creep Test @ 150°C %									100•				
Elongation test									10•				

† Use Condition A with full-strength solution of Igepal CO 630 or equivalent, as defined in ASTM D1693.
†† Use Condition B with full-strength solution of Igepal CO 630 or equivalent, as defined in ASTM D1693.
‡ In lieu of testing finished cable jackets, a certification by the manufacturer of the polyethylene compound that this requirement has been complied with shall suffice.
• This test can be used as an alternate to the set test to check cure for CSPE-HD jackets only. Only one test (unaged set or hot creep) need be performed.

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Table 7-2
HALOGEN FREE JACKET REQUIREMENTS

Test Type	Thermoplastic Type I	Thermoset Type I	Thermoset Type II
PHYSICAL REQUIREMENTS			
Unaged Tensile Properties			
Tensile Strength, min. (psi)	1400	1400	1600
(MPa)	9.65	9.65	11.0
Elongation @ Rupture (min %)	100	150	150
Oven Aged Tensile Properties			
Oven Conditions			
Time (hr.)	168	168	168
Temp (°C ± 1°C)	100	121	121
Tensile Strength			
(min % retained)	75	75	85
Elongation @ Rupture			
(min % retained)	60	60	75
Hot Creep Test (150°C ± 2°C)			
Elongation, Max. (%)	N/A	100	100
Creep Set, Max. (%)	N/A	10	10
MECHANICAL REQUIREMENTS			
Heat Deformation			
(1000 gm. wt)			
Temperature (°C ± 1°)	90	N/A	N/A
Deformation, max (%)	25	N/A	N/A
Cold Bend			
Temperature (°C ± 2°C)	-25	-25	-25
Gravimetric Water Absorption			
Absorption (mg/in^2), max.	N/A	N/A	50
MATERIAL COMBUSTION REQUIREMENTS			
Acid Gas Equivalent			
Maximum (%)	2	2	2
Halogen Content			
Maximum (%)	0.2	0.2	0.2
Smoke Generation			
(80 ± 5 mil plaque)			
Flaming Mode Ds4 max	50	50	50
Dm max	250	250	250
Nonflaming Mode D_s4 max	50	50	50
Dm max	350	350	350
Vertical Tray Flame/Smoke Test			
(Jacketed Completed Cable)	Pass	Pass	Pass
OPTIONAL OIL-RESISTANCE REQUIREMENTS			
Oil* Aged Tensile Properties			
Oven Conditions			
Time (hrs.)	4	18	18
Temp. (°C ± 1°C)	70	121	121
Tensile Strength			
(min % retained)	60	50	50
Elongation @ Rupture			
(min % retained)	60	50	50

*Use ASTM Oil #2 or IRM902

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7.1.20 Jacket Thickness

The jacket thicknesses shall be not less than the applicable thickness given in Table 7-3. The thickness of an optional jacket on individual insulated conductors of multiple conductor cables shall be in accordance with Table 7-4. The appropriate jacket thickness shall be determined in accordance with Appendix C "Procedures for Determining Dimensional Requirements of Jackets & Associated Coverings."

7.1.21 Jacket Irregularity Inspection

A nonconducting jacket over the completed cable shall withstand an alternating current spark test voltage. The voltage shall be applied between an electrode at the outside surface of the jacket and the underlying shield conductor. The cable shield shall be connected to ground during the test. The spark test shall be conducted in accordance with ICEA T-27-581/NEMA WC-53.

Table 7-3
THICKNESS OF OVERALL JACKET OF SINGLE OR MULTIPLE-CONDUCTOR CABLE (FOR ALL VOLTAGES AND ALL USES)

Calculated Diameter of Cable Under Jacket		Minimum Jacket Thickness	
inches	mm	mils	mm
0.700 or less	17.78 or less	55	1.40
0.701-1.500	17.81 - 38.10	70	1.78
1.501-2.500	38.13 - 63.50	100	2.54
2.501 and larger	63.53 and larger	125	3.17

Table 7-4
THICKNESS OF OPTIONAL JACKET ON INDIVIDUAL CONDUCTORS OF MULTIPLE-CONDUCTOR CABLES UNDER A COMMON JACKET

Calculated Diameter of Individual Conductor Under Jacket		Minimum Jacket Thickness*	
inches	mm	mils	mm
0.700 or less	10.80 or less	25	0.64
0.701-1.500	17.81 - 38.10	45	1.14
1.501-2.500	38.13 - 63.50	70	1.78

* These thicknesses apply to jackets only and do not apply to colored coatings on the individual conductors of multiple-conductor cables.

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7.2 METALLIC AND ASSOCIATED COVERINGS

7.2.1 General

The requirements given in this section apply to cables applied under usual installation, operating, and service conditions.

Where unusual installation, operating, or service conditions exist, these conditions should be defined in order to allow any necessary cable design modifications before a final design is completed. In classifying jackets and sheaths in these standards, the term "jacket" refers to nonmetallic coverings and "sheath" refers to continuous metallic coverings.

The types of coverings and conditions of installation are as follows:

1. Metallic sheath, lead or aluminum.
    a. In conduit, ducts, troughs, cable trays or raceways
    b. Suspended from aerial messenger
    c. For other types of installations when suitably protected by metal armor or nonmetallic coverings.

2. Flat metal tape armor.
    a. In conduit, ducts, troughs, cable trays or raceways
    b. Direct burial in earth
    c. Clamped in shafts
    d. Suspended from aerial messenger

Plain- or galvanized-steel tape armor, depending upon soil and water conditions, with a supplemental covering for corrosion protection is suitable for use on cables for below-grade, wet locations and for shaft installations where the cable can be clamped at intervals.

Galvanized-steel tape armor without supplemental coverings is suitable for use on cables to be suspended from an aerial messenger strand.

3. Interlocked metal tape armor or continuously corrugated metal armor.
    a. Direct burial in earth
    b. Troughs, racks, cable trays or raceways
    c. Clamped in shafts
    d. Suspended from aerial messenger.

Interlocked metal tape armor without an outer covering, but with either a bedding or a jacket under the armor, is suitable for cables for indoor use and for outdoor aerial service.

Interlocked metal tape armor with either a bedding or a jacket under the armor and with either a supplemental covering for corrosion protection or a thermoplastic jacket over the armor is suitable for underground installations.

4. Galvanized steel wire armor.
    a. Submarine cable.
    b. Dredge cable.
    c. Vertical riser, borehole, and shaft cable for end suspension.
    d. Direct burial in trenches and subjected to unusual longitudinal stress.

A covering is required for direct burial cable. Coverings, typically servings, are required on submarine, borehole, and shaft cable where severe installation and service conditions exist. Such coverings may

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also be used where the conditions of transportation require protection for the galvanizing on the armor wires. Coverings are not required on dredge and vertical riser cable.

7.2.1.1 Divisions

Three divisions define specific installations:

Division I (See 7.3) concerns materials, construction, and requirements for metallic and associated coverings recommended for use under normal conditions of installation, operation, and maintenance of power cables. It also covers submarine cables.

The requirements of Division I as pertaining to quality of materials, design, and construction apply also to the following Divisions II and III, except as to particular details expressly set forth in each division or as otherwise modified.

Division II (See 7.4.) concerns round wire armor for borehole, dredge, shaft, and vertical riser cables.

Division III (See 7.5.) concerns round wire armor for buried cable.

7.3 DIVISION I

7.3.1 Metallic Sheaths

A lead or smooth aluminum sheath, with or without outer supplementary protection, shall be used when an impervious covering is required.

7.3.1.1 Lead Sheaths

A sheath composed of commercially pure lead or an alloyed lead shall be tightly formed around the core of the cable. The lead shall be determined by the manufacturer and shall meet the requirements of ASTM B29 unless other compositions and test requirements are agreed upon between the manufacturer and the user. When chemical lead or copper lead is used, the mass fraction of the copper content shall be not less than 0.040 % and not more than 0.080 %.

The minimum point thickness of a lead sheath not intended to have an overlying jacket shall be in accordance with Table 7-5.

The minimum point thickness of a lead sheath having an overlying jacket of either thermoset or thermoplastic compound shall be in accordance with Table 7-6.

The thickness shall be measured in accordance with Section 9. There are situations where the above thicknesses may require an increase, especially on the smaller sizes of cable, such as when several cables are to be pulled together in one duct, or the sections to be pulled are extra long, or the handling during installation is severe or awkward, as in some transformer vaults.

When the sheath does not meet the requirements of these standards it shall not be repaired, but the lead may be stripped from the entire length of the cable and the cable resheathed. Lead stripped from new cable may be reused, and when so used, it shall comply with the requirements given herein.

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Table 7-5
THICKNESS OF LEAD SHEATH ON UNJACKETED CABLES

Calculated Diameter of Core*		Minimum Point Thickness of Sheath	
inches	mm	mils	mm
0.425 or less	10.80 or less	40†	1.02†
0.426 - 0.700	10.82 - 17.78	60†	1.52†
0.701 - 1.050	17.81 - 26.67	70	1.78
1.051 - 1.500	26.70 - 38.10	85	2.16
1.501 - 2.000	38.13 - 50.80	100	2.54
2.001 - 3.000	50.83 - 76.20	115	2.92
3.001 and larger	76.23 and larger	125	3.18

* The thickness of lead sheath for flat twin cable shall be based on the calculated major core diameter.
† In submarine cables, the minimum point thickness shall be 70 mils (1.78 mm).

Table 7-6
THICKNESS OF LEAD SHEATH FOR CABLES HAVING A CROSS-LINKED OR THERMOPLASTIC JACKET OVER LEAD SHEATH

Calculated Diameter of Core*		Minimum Point Thickness of Sheath	
inches	mm	mils	mm
0.425 or less	10.80 or less	40†	1.02†
0.426 - 0.700	10.82 - 17.78	50†	1.27†
0.701 - 1.050	17.81 - 26.67	65	1.65
1.051 - 1.500	26.70 - 38.10	75	1.91
1.501 - 2.000	38.13 - 50.80	85	2.16
2.001 - 3.000	50.83 - 76.20	100	2.54
3.001 & larger	76.23 & larger	115	2.92

* The thickness of lead sheath for flat twin cable shall be based on the calculated major core diameter.
† In submarine cables, the minimum point thickness shall be 65 mils (1.65 mm).

7.3.1.2 Aluminum Sheaths

A smooth sheath of aluminum alloy 1060 or 1350 or other alloy having not less than 99.5 % aluminum shall be tightly formed around the core of the cable. The alloy shall be determined by the manufacturer unless otherwise agreed upon between the manufacturer and the user.

The minimum point thickness of the aluminum sheath shall be in accordance with Table 7-7. The thickness shall be measured in accordance with Section 9.

When the sheath does not meet the requirements of these standards, it shall not be repaired, but the aluminum may be stripped from the entire length of the cable and the cable resheathed.

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Table 7-7
THICKNESS OF SMOOTH ALUMINUM SHEATH

Calculated Diameter of Core*		Minimum Point Thickness of Sheath	
Inches	**mm**	**mils**	**mm**
0.400 or less	10.16 or less	35	0.89
0.401 - 0.740	10.19 - 18.80	40	1.02
0.741 - 1.050	18.82 - 26.67	50	1.27
1.051 - 1.300	26.70 - 33.02	60	1.52
1.301 - 1.550	33.05 - 39.37	70	1.78
1.551 - 1.800	39.40 - 45.72	75	1.91
1.801 - 2.050	45.75 - 52.07	85	2.16
2.051 - 2.300	52.10 - 58.42	95	2.41
2.301 - 2.550	58.45 - 64.77	105	2.67
2.551 - 2.800	64.80 - 71.12	115	2.92
2.801 - 3.050	71.15 - 77.47	125	3.18
3.051 - 3.300	77.50 - 83.82	130	3.30
3.301 - 3.550	83.85 - 90.17	140	3.56
3.551 - 3.800	90.30 - 96.52	150	3.81
3.801 - 4.050	96.55 - 102.9	160	4.06

* The thickness of the aluminum sheath for flat twin cable shall be based on the calculated major core diameter.

7.3.2 Flat Steel Tape Armor

Plain and zinc-coated flat steel strip in coils, applied in accordance with 7.3.2.4, shall be used as flat metal tape armor for cables. Supplementary outer coverings for corrosion or other protection shall be applied when required.

7.3.2.1 Tensile Strength and Elongation

The plain and zinc-coated strip shall have a tensile strength of not less than 40000 psi (276 MPa) nor more than 70000 psi (482 MPa). The tensile strength shall be determined on longitudinal specimens consisting of the full width of the strip when practical or on a straight specimen slit from the center of the strip. The strip shall have an elongation of not less than 10 percent in 10 inches (254 mm). The elongation shall be the permanent increase in length of a marked section of the strip, originally 10 inches (254 mm) in length, and shall be determined after the specimen has fractured. All tests shall be made prior to application of the strip to the cable.

7.3.2.2 Galvanizing (Zinc Coating) Test

The zinc coating shall be applied by either the hot-dip or the electro-galvanizing process such that all surfaces of the finished tape width are coated, including edges. The weight of zinc coating shall be determined before application of the strip to the cable. The strip shall have a minimum weight of coating of 0.35 oz/ft^2 (106.8 g/m^2) of exposed surface. The weight of coating shall be determined in accordance with the method described in ASTM A90.

The zinc coating shall remain adherent without flaking or spalling when the strip is subjected to a 180-degree bend over a mandrel of 0.33 inch (8.38 mm) diameter. The zinc coating shall be considered as meeting this requirement if, when the strip is bent around the specified mandrel, the coating does not flake and none of it can be removed from the strip by rubbing with the fingers.

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Loosening or detachment during the adherence test of superficial, small particles of zinc formed by mechanical polishing of the surface of the zinc-coated strip shall not constitute failure.

7.3.2.3 Tape Size

The nominal width of the metal tape shall be not greater than that specified in Table 7-8. For nominal width dimensions of 1.000 inch (25.4 mm) or less, the tolerance shall be ±0.031 inch (0.79 mm). For nominal widths greater than 1.000 inch (25.4 mm), the tolerance shall be ±0.047 inch (1.19 mm).

Table 7-8
WIDTH OF STEEL TAPE FOR FLAT ARMOR
(PLAIN OR ZINC COATED)

Calculated Diameter of Cable Under Bedding*		Nominal Width of Steel Tape	
inches	mm	inches	mm
0.450 or less	11.43 or less	0.750	19.0
0.451 - 1.000	11.46 - 25.40	1.000	25.4
1.001 - 1.400	25.43 - 35.56	1.250	31.8
1.401 - 2.000	35.59 - 50.80	1.500	38.1
2.001 - 3.500	50.83 - 88.90	2.000	50.8
3.501 & larger	88.93 & larger	3.000	76.2

*For flat twin cable, the nominal width shall be based on the calculated major core diameter.

The nominal thickness of the metal tape shall be not less than that given in Table 7-9. See Section 9 for method of measuring metal tape thickness. The tolerance in the nominal thickness of the tape shall be ±3 mils (0.08 mm).

For zinc coated steel tape the specified nominal thickness and tolerance shall apply to the stripped bare metal. The zinc-coated tape shall not be more than 20 % thicker than the stripped bare metal tape thickness.

Table 7-9
THICKNESS OF STEEL TAPE FOR FLAT ARMOR
(PLAIN OR ZINC-COATED)

Calculated Diameter of Cable Under Bedding*		Nominal Thickness of Steel Tape	
inches	mm	mils	mm
1.000 or less	25.40 or less	20	0.51
1.001 & larger	25.43 & larger	30	0.76

*For flat twin cable, the nominal thickness shall be based on the calculated major core diameter.

7.3.2.4 Application, Lay, and Spacing of Tapes

Two metal tapes shall be applied helically in the same direction over the bedding except that they may be applied in opposite directions where the total area of the conductors is less than 50 kcmil (25.34 mm^2). When the bedding is helically applied tape, yarn or roving, the direction of lay of the inner metal tape shall be opposite to that of the outer bedding layer.

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The maximum space between the turns of the metal armor tapes shall not exceed 20 % of the width of the tape or 0.200 inch (5.08 mm), whichever is greater. When the two metal armor tapes are applied in the same direction, the outer tape shall be approximately centered over the space between the turns of the inner tape.

During or prior to application, the tapes shall be flushed with a suitable compound to deter corrosion unless a supplementary corrosion protective covering is applied.

7.3.3 Interlocked Metal Tape Armor

Flat metallic strip in coils shall be formed as interlocking armor for electrical cables. All tests shall be made prior to the application of the strip to the cable.

7.3.3.1 Steel Tape

Plain steel tape may be used for interlocked armor when a supplemental outer protective covering is furnished. Otherwise, the steel tape (except stainless) shall be zinc-coated. The requirements for the tensile strength of flat steel tape and for the zinc coating shall be in accordance with 7.3.2.

The nominal width of metal tape shall not be greater than that specified in Table 7-10. For any nominal width of metal tape used, the width tolerance shall be +0.010 in (0.25 mm) and
- 0.005 in (0.13 mm).

Table 7-10
WIDTH OF METAL TAPE FOR INTERLOCKED ARMOR

Calculated Diameter of Cable Under Armor		Nominal Width of Metal Tape Armor	
inches	mm	inches	mm
0 - 0.500	0 - 12.70	0.500	12.7
0.501 - 1.000	12.73 - 25.40	0.750	19.0
1.001 - 2.000	25.43 - 50.80	0.875	22.2
2.001 & larger	50.83 & larger	1.000	25.4

The nominal thickness of metal tape shall be not less than that given in Table 7-11. See Section 9 for method of measuring metal tape thickness. The tolerance in nominal thickness of the tape shall be ±3 mils (0.08 mm).

For zinc coated steel tape the specified nominal thickness and tolerance shall apply to the stripped bare metal. The zinc-coated tape shall not be more than 20% thicker than the stripped bare metal tape thickness.

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Table 7-11
THICKNESS OF METAL TAPE FOR INTERLOCKED ARMOR

Calculated Diameter of Cable Under Armor		Nominal Thickness			
		Cupro-nickel, Brass, Steel, Bronze, Stainless Steel, and Monel Tape		Aluminum and Zinc Tape	
inches	mm	mils	mm	mils	mm
1.500 or less	38.10 or less	20	0.51	25	0.64
1.501 & larger	38.13 & larger	25	0.64	30	0.76

7.3.3.2 Non-magnetic Tape

When non-magnetic tapes, such as aluminum, brass, bronze, cupro-nickel, zinc or stainless steel tapes are used, the width shall be in accordance with Table 7-10, except that the tolerance for aluminum shall be ±0.010 inch (0.25 mm)), and the thickness shall be in accordance with Table 7-11.

Representative values of tensile strength and elongation for the nonmagnetic metals are given in Appendix E.

7.3.4 Continuously Corrugated Metal Armor

Continuously corrugated armor shall be constructed by using a flat metal tape which is longitudinally folded around the cable core, seam welded, and corrugated or by applying over the cable core a seamless sheath or tube which is then corrugated. Supplementary outer coverings for corrosion or other protection of the armor shall be applied when required.

7.3.4.1 Type of Metal

When metal armor is formed from a flat metal tape, the tapes used shall be aluminum, copper, steel or alloys thereof.

When metal armor is formed by applying a seamless sheath or tube the metal shall be aluminum or an aluminum alloy.

7.3.4.2 Thickness

The minimum thickness of tape or of the sheath or tube before corrugation shall be as shown in Table 7-12.

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Table 7-12
MINIMUM THICKNESS OF METAL FOR CORRUGATED ARMOR

Calculated Diameter of Cable Under Armor		Aluminum		Copper		Steel	
inches	mm	mils	mm	mils	mm	mils	mm
0 - 2.180	0 - 55.37	22	0.56	..	...	..	...
2.181 - 3.190	55.40 - 81.03	29	0.74	..	...	..	...
3.191 - 4.200	81.05 - 106.70	34	0.86	..	...	..	...
0 - 2.365	0 - 60.07	..	...	17	0.43	..	...
2.366 - 3.545	60.10 - 90.04	..	...	21	0.53	..	...
3.546 - 4.200	90.07 - 106.70	..	...	25	0.64	..	...
0 - 1.905	0 - 48.39	..	...	..	...	16	0.41
1.906 - 3.050	48.41 - 77.47	..	...	..	...	20	0.51
3.051 - 4.200	77.50 - 106.70	...	...	..	...	24	0.61

7.3.4.3 Flexibility

The armored cable shall be capable of being bent around a mandrel having a diameter of 14 times the cable diameter. The armor shall show no evidence of openings, splits, or cracks visible to the unaided eye. The test shall be conducted in accordance with ICEA T-27-581/NEMA WC 53.

7.3.5 Galvanized Steel Wire Armor For Submarine Cables

Zinc-coated low-carbon-steel wire shall be used for the armoring of submarine cables. For wire armor for special uses such as on dredge, borehole, vertical riser, shaft and buried land cables, see Divisions II and III (7.4 and 7.5). All tests shall be made prior to application of the wire to the cable.

7.3.5.1 Physical Requirements

The zinc-coated wire shall be uniform in diameter and free from cracks, splints or other flaws.

The zinc-coated wire shall have a tensile strength of not less than 50,000 psi (345 MPa) and not more than 70,000 psi (483 MPa). The tensile strength shall be tested in accordance with ASTM E 8.

The zinc-coated wire shall have an elongation of not less than 10 percent in 10 inches (254 mm). The elongation shall be the permanent increase in length of a marked section of the wire originally 10 inches (254 mm) in length and shall be determined after the specimen has fractured.

The zinc-coated wire shall withstand, without fracture, the minimum number of twists specified in Table 7-13. This test shall be made on a sample of wire having an initial length of 6 inches (152 mm) between jaws of a standard torsion machine or equivalent with one head of the machine movable horizontally. The effective speed of rotation shall not exceed 60 rpm.

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Table 7-13
NUMBER OF TWISTS (TORSION TEST)

Nominal Wire Diameter		Minimum Number of Twists
mils	mm	
238 - 166	6.05 - 4.22	7
165 - 110	4.19 - 2.79	10
109 - 65	2.77 - 1.65	14

7.3.5.2 Galvanizing (Zinc Coating) Tests

The zinc coating shall be applied by either the hot-dip or the electro-galvanizing process.

The weight of zinc coating shall be determined before the wire is applied to the cable. The wire shall have a minimum weight of coating per square foot of uncoated wire surface in accordance with Table 7-14. The zinc coating shall be tested for weight by a stripping test in accordance with ASTM A 90.

Table 7-14
MINIMUM WEIGHTS OF ZINC COATING

Size and Nominal Diameter of Coated Wire			Minimum Weight of Zinc Coating per Area of Exposed Surface	
Size BWG*	Diameter mils	Diameter mm	Ounces per Square Foot	Grams per Square Meter
4	238	6.05	1.00	305
5	220	5.59	1.00	305
6	203	5.16	1.00	305
8	165	4.19	0.90	275
10	134	3.40	0.80	244
12	109	2.77	0.80	244
14	83	2.11	0.60	183

* Birmingham Wire Gauge

The zinc coating shall remain adherent when the wire is wrapped at a rate of not more than 15 turns per minute in a closed helix of at least two turns around a cylindrical mandrel of the diameter specified in Table 7-15.

The zinc coating shall be considered as meeting this requirement if, when the wire is wrapped about the specified mandrel, the coating does not flake and none of it can be removed from the wire by rubbing it with the fingers. Loosening or detachment during the adherence test of superficial, small particles of zinc formed by mechanical polishing of the surface of zinc-coated wire shall not constitute failure.

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Table 7-15
MANDREL DIAMETER FOR ADHERENCE OF COATING TESTS

Wire Diameter		
mils	mm	Mandrel Diameter
less than 134	less than 3.40	2 times wire diameter
134 & larger	3.40 & larger	3 times wire diameter

7.3.5.3 Size of Armor Wire

The size of armor wire for submarine cables shall be in accordance with Table 7-16. If the service requirements are exceptionally severe, larger sizes of armor wire may be required. Diameter tolerances for the armor wire sizes are given in Table 7-17.

Table 7-16
SIZE OF GALVANIZED STEEL ARMOR FOR SUBMARINE CABLE

Calculated Diameter of Cable Under Bedding		Nominal Size of Armor Wire		
inches	mm	BWG	mils	mm
0-0.750	0-19.05	12	109	2.77
0.751-1.000	19.08-25.40	10	134	3.40
1.001-1.700	25.43-43.18	8	165	4.19
1.701-2.500	43.21-63.50	6	203	5.16
2.501 & larger	63.53 & larger	4	238	6.05

Table 7-17
TOLERANCES IN DIAMETER

Nominal Diameter of Coated Wire		Tolerance	
mils	mm	mm	mils
65 through 108	1.65 through 2.75	±3	±0.08
109 through 165	2.77 through 4.20	±4	±0.10
166 through 238	4.22 through 6.25	±5	±0.13

7.3.5.4 Lay

"Lay" is defined as follows: "The lay of any helical element of a cable is the axial length of one turn of a helix of that element."

The length of lay of the armor wires of Division I cables shall be not less than seven nor more than twelve times their pitch diameter for all constructions except for dredge cable. For dredge cable, see 7.4.2.

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Successive layers of jute and armor shall be laid in opposite directions. The direction of lay of the armor wires shall be so chosen that birdcaging of the cable being armored shall be reduced to a minimum.

7.3.6 Bedding Over Cable Cores To Be Metallic Armored

7.3.6.1 Unsheathed or Unjacketed Cores

When an unsheathed and unjacketed cable core, is to have a flat steel tape or round wire armor applied, it shall be protected by suitable tape (compound-filled or equivalent) plus other bedding having a thickness in accordance with Table 7-18. When an interlocked metal tape armor or a continuously corrugated armor is to be applied, only a suitable tape bedding is required.

A compound-filled tape is a fabric cloth treated on one or both sides with a non-conducting compound. When used, a tape shall be applied helically and overlapped not less than 10 percent of its width. (For cores having a diameter smaller than 0.300 inch (7.62 mm), serving(s) of jute or equivalent yarns may be substituted for the tape.)

When flat steel tape, interlocked tape, or round wire armor will remain unjacketed and the cable is intended for use in below-grade or potentially wet environments, cores having beddings of tapes or jute yarn or other roving shall be run through a hot asphalt compound or equivalent saturant. When intended for installation in permanently dry indoor above-grade locations, saturant compounds need not be applied to the core beddings.

When the armor will have an outer protective jacket, the cable core, with or without metallic shield tape and/or beddings, does not require exposure to saturant compounds.

The nominal thickness of the bedding shall be in accordance with Table 7-18. The thickness shall be determined by the use of a diameter tape and shall be considered as one-half of the difference in measurements under and over the bedding.

Table 7-18
THICKNESS OF BEDDING UNDER METALLIC ARMOR FOR UNSHEATHED AND UNJACKETED CORES

Calculated Diameter of Cable Under Bedding		Under Flat Steel Tape Armor		Under Round Wire Armor	
		Nominal Bedding thickness		Nominal Bedding thickness	
inches	mm	mils	mm	mils	mm
0.450 & less	11.43 & less	30	0.76	80	2.03
0.451 - 0.750	11.46 - 19.05	45	1.14	80	2.03
0.751 - 1.000	19.08 - 25.40	45	1.14	95	2.41
1.001 - 2.500	25.43 - 63.50	65	1.65	110	2.79
2.501 & larger	63.53 & larger	65	1.65	125	3.18

7.3.6.2 Jacketed Cores or Sheathed Non-jacketed Cores

When a jacketed core is to be armored, any suitable tape or serving of jute or other roving may be used as a bedding if necessary.

When a core with an unjacketed sheath is to have a flat steel tape or round wire armor, it shall be protected with a suitable bedding having a thickness in accordance with Table 7-18. When an interlocked

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tape or continuously corrugated armor is to be applied, any suitable separator tape may be used over the sheath.

When the applied flat steel tape, interlocked tape, or round wire armor will remain unjacketed and the cable is intended for installation in below-grade or potentially wet environments, the metallic sheath and all bedding layers applied over the sheath or core jacket shall be run through a hot asphalt or tar compound, or equivalent saturant. When intended for installation in a permanently dry indoor above-grade locations, a cable core bedding does not require exposure to saturant compounds.

7.3.7 Outer Servings

7.3.7.1 Over Metallic Sheath (Without Armor or Jacket)

When specified for mechanical protection of the metallic sheath, the sheathed cable shall be run through hot asphalt or equivalent saturant, and served with one (or two if specified) closely wound lay of No. 16/3 impregnated jute yarn, or plied jute, or other servings of equivalent thickness. If two servings are used, they shall be closely wound and applied with opposite directions of lay. Each serving may be run through hot asphalt or equivalent saturant. For either one or two servings, the outer serving shall be further coated with some suitable material if required to prevent sticking of adjacent turns of the cable when wound on a reel.

The nominal thickness of the single and double servings applied over metallic sheathed cable for mechanical protection shall be as given in Table 7-19.

Table 7-19
THICKNESS OF SERVINGS OVER METALLIC SHEATH (WITHOUT METALLIC ARMOR)

Calculated Diameter of Cable Under Serving*		Nominal Thickness of Serving One Serving		Two Servings	
inches	mm	mils	mm	mils	mm
1.000 or less	2.540 or less	65	1.65	95	2.41
1.001 – 2.50	25.43 – 63.50	65	1.65	110	2.79
2.501 & larger	63.53 & larger	65	1.65	125	3.18

*The thickness of servings over the metallic sheath of a flat twin cable shall be based on the calculated major core diameter.

7.3.7.2 Over Metallic Armored Cables

When an outer serving is required, the armored cable shall first be run through hot asphalt or equivalent coating, then served with a layer of No. 16/3 impregnated jute, or plied yarn, or other servings of equivalent thickness, applied with a close lay. The cable shall then be run through hot asphalt or equivalent saturant and finished by running through some suitable material if required to prevent sticking of adjacent turns of the cable when wound on a reel.

The direction of lay of the serving shall be opposite to that of the underlying armor.

7.3.8 Cross-linked Jackets Over Metallic Sheaths and Armors

A cross-linked jacket, when applied over a smooth metallic sheath or armor, may be either a reinforced or a non-reinforced type.

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7.3.8.1 Reinforced Cross-Linked Jacket

When a reinforced cross-linked jacket is applied, it shall consist of a combination of treated fibrous reinforcing tapes and a neoprene jacket compound suitable for exposure to sunlight.

The physical properties of the neoprene jacket compound shall meet the following requirements:

Physical Requirements (see Section 9)	
Tensile strength, minimum, psi	1200
MPa	8.27
Elongation at rupture, minimum, percent	250
Set, maximum percent	20
Aging Requirements	
After air oven test at 70°C ±1°C for 168 hr	
Tensile strength, minimum psi	1000
MPa	6.89
Elongation at rupture, minimum, percent	200
After oil immersion test at 121°C ±1°C for 18 hr	
Tensile strength and elongation	
minimum percentage of unaged value	60

These tests shall be made on samples removed from the finished cable or, where this is impractical, on a sample of the neoprene jacket compound which is identical with that on the cable and which has been given the same treatment as the neoprene jacket.

The minimum thickness of the reinforced crosslinked jacket shall be not less than that specified in Table 7-20.

Table 7-20
MINIMUM THICKNESS OF REINFORCED CROSS-LINKED JACKET OVER METALLIC SHEATHS AND ARMOR

Calculated Diameter Under Jacket		Minimum Thickness	
inches	**mm**	**mils**	**mm**
1.500 or less	38.10 or less	60	1.52
1.501 - 3.000	38.13 - 76.20	85	2.16
3.001 and over	76.23 and over	110	2.79

7.3.8.2 Non-Reinforced Crosslinked Jacket

A non-reinforced crosslinked jacket, when used, shall be one of the following materials extruded over the metallic sheath or armor and shall meet the applicable requirements of Section 7:

Neoprene, Heavy Duty Black
Nitrile-butadiene/Polyvinyl Chloride, Heavy Duty
Chlorosulfonated Polyethylene, Heavy Duty
Chlorinated Polyethylene, Heavy Duty, Crosslinked

A separator in accordance with 7.1.19 shall be permitted to be used over the armor,

The minimum thickness of the non-reinforced crosslinked jacket shall be not less than that specified in Table 7-21.

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The crosslinked jacket over a sheath or an armor shall not have irregularities as determined by the procedure given in ICEA T-27-581. The methods to be used are:

Method A for Neoprene
Method B for Nitrile-butadiene/PVC and Chlorosulfonated Polyethylene
Method C for Crosslinked Chlorinated Polyethylene

7.3.9 Thermoplastic Jackets Over Metallic Sheaths or Armors

Thermoplastic jackets, when used, shall be one of the following materials extruded over the metallic sheath or armor and shall fit tightly thereto:

Polyvinyl chloride meeting the requirements given in Section 7, except that the cold bend requirements shall be as stated below, or

Black chlorinated polyethylene meeting the requirements given in Section 7, except that the cold bend requirements shall be as stated below, or

Black polyethylene meeting the requirements given in Section 7 for low & linear low density, or medium density, or high density material.

The minimum thickness of the thermoplastic jacket over metallic sheaths or armors shall be not less than that specified in Table 7-21.

Table 7-21
THICKNESS OF EXTRUDED NON-REINFORCED CROSSLINKED JACKETS AND EXTRUDED THERMOPLASTIC JACKETS OVER METALLIC SHEATHS AND ARMORS

Calculated Diameter of Cable Under The Jacket		Jacket Thickness			
		Over Sheath or Flat Tape and Round Wire Armor		Over Interlocked or Corrugated Armor	
inches	mm	mils	mm	mils	mm
0.750 or less	19.05 or less	40	1.02	40	1.02
0.751 - 1.500	19.08 - 38.10	50	1.27	40	1.02
1.501 - 2.250	38.13 - 57.15	65	1.65	50	1.27
2.251 - 3.000	57.18 - 76.20	75	1.91	60	1.52
3.001 & larger	76.23 & larger	90	2.29	70	1.78

The tightness of a polyethylene jacket over a sheath shall be tested in accordance with Section 9. No movement of the 2-inch (50.8 mm) ring shall take place within a period of one minute following the application of a force to the upper end of the sample. The force, in the form of a weight, to be applied shall be equal to 10 lb (4.54 kg) per inch (25.4 mm) of outside diameter of the metallic sheath minus the weight of the prepared sample, rounded off to the nearer half pound (0.23 kg).

The thermoplastic jacket over a sheath or an armor shall not have irregularities as determined by the procedure given in ICEA T-27-581. The methods to be used are:

Method B for Thermoplastic Chlorinated Polyethylene
Method C for Polyvinyl Chloride and for Polyethylene

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When required, the manufacturer shall submit evidence that when similar thermoplastic jacketed cable has been subjected to the same cold bend test with the same frequency as required for the underlying core and at a test temperature of minus 10°C or colder, the jacket shall show no cracks visible to the normal unaided eye.(See Section 9)

7.4 DIVISION II

The requirements of Division I pertaining to quality of materials, design, and construction apply also to the borehole, dredge, shaft, and vertical riser cables except as expressly set forth in the following sections for the respective types of cable, or as otherwise modified.

7.4.1 Borehole Cable (Suspended at One End Only)

7.4.1.1 Armor

Galvanized round steel wire shall be used for borehole cable.

The size of the armor wire shall be as given in Table 7-22. The tensile safety factor [based on 50000 psi (345 MPa)] shall be not less than five. If the required tensile safety factor is not maintained, the next larger size wire given in the table should be used.

The length of lay of the armor wires shall be not less than seven nor more than twelve times their pitch diameter. The armor shall be applied closely without appreciable space between the wires.

"Lay" is defined as: "The lay of any helical element of a cable is the axial length of one turn of a helix of that element."

7.4.1.2 Wire Band Serving

Where wire band servings over the armor are required for cable suspended vertically from one end, No. 12 BWG (109 mils) (2.77 mm) wire shall be used. The length of the serving band and the spacing of the band throughout the length of the cable shall be in accordance with Table 7-26.

The wire bands shall be applied sufficiently tight to prevent their movement along the cable during installation handling.

Table 7-22
SIZE OF GALVANIZED STEEL ARMOR WIRE FOR BOREHOLE CABLE

Calculated Diameter of Cable Under Bedding		Nominal Size of Armor Wire		
inches	mm	BWG	mils	mm
0.750 or less	19.05 or less	12	109	2.77
0.751 - 1.000	19.08 - 25.40	10	134	3.40
1.001 - 1.700	25.43 - 43.18	8	165	4.19
1.701 - 2.500	43.21 - 63.50	6	203	5.16
2.501 & larger	63.53 & larger	4	238	6.05

7.4.2 Dredge Cable

7.4.2.1 Armor

Galvanized round steel wire shall be used for dredge cable and shall be applied with a short lay. The pitch ratio limits shall be in accordance with Table 7-23.

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Table 7-23
PITCH RATIO OF GALVANIZED WIRE ARMOR FOR DREDGE CABLE

Calculated Diameter Over the Armor Wires		Minimum Pitch Ratio
inches	mm	
0-2.500 or less	0-63.50 or less	2.5
2.501 & larger	63.53 & larger	3.0

The pitch ratio is taken as the quotient resulting from dividing the length of lay of the armor wires by the pitch diameter of the armor wires. Where unusual service conditions exist, it may be desirable to modify the above pitch ratio. If so, it should be defined before the cable design is finalized.

The size of the armor wires shall be as given in Table 7-24.

Table 7-24
SIZE OF GALVANIZED STEEL ARMOR WIRE FOR DREDGE CABLE

Calculated Diameter of Cable Under Bedding		Nominal Size of Armor Wire		
inches	mm	BWG	mils	mm
1.700 or less	43.18 or less	12	109	2.77
1.701 - 2.500	43.21 - 63.50	10	134	3.40
2.501 & larger	63.53 & larger	8	165	4.19

7.4.3 Shaft Cable

If the shaft cable is suspended from one end during installation or thereafter, galvanized round steel wire armor shall be used.

7.4.3.1 Tape or Wire Armor For Clamped Cables

When shaft cable is clamped to the shaft structure or wall, the metallic coverings used (either tape or wire) shall comply with the applicable requirements of 7.3.

7.4.3.2 Wire Armor For Vertically Suspended Cables

The size of the armor wires for cables suspended at one end shall be as given in Table 7-25, but the tensile safety factor shall be not less than five.

Wire band servings in accordance with 7.4.1.2 shall be applied.

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Table 7-25
SIZE OF GALVANIZED STEEL ARMOR WIRE FOR SHAFT CABLE AND VERTICAL RISER CABLE

Calculated Diameter of Cable Under Bedding		Nominal Size of Armor Wire		
inches	mm	BWG	mils	mm
1.000 or less	25.40 or less	12	109	2.77
1.001-1.700	25.43-43.18	10	134	3.40
1.701-2.500	43.21-63.50	8	165	4.19
2.501 & larger	63.53 & larger	6	203	5.16

Table 7-26
SPACING AND LENGTH OF BAND SERVINGS

Calculated Diameter Over the Armor Wire		Maximum Band Spacing		Length of Band	
Inches	mm	feet	meters	inches	mm
0-1.500	0-38.10	50	15.2	3	76
1.501-2.500	38.13-63.50	35	10.7	4	102
2.501 & larger	63.53 & larger	25	7.6	4	102

7.4.4 Vertical Riser Cable

Vertical riser cable is for installation within buildings and is suspended at one end only.

7.4.4.1 Armor

Galvanized round steel wires shall be used for vertical riser cables.

7.4.4.2 Size of Armor Wire

For non-sheathed cables, the armor wires shall be sized in accordance with Table 7-25 for shaft cable. The tensile safety factor [based on 50000 psi (345 MPa)] shall be not less than seven. If the required tensile safety factor is not maintained, the next larger size wire given in the table should be used. Wire band servings in accordance with 7.4.1.2 shall be applied.

For sheathed cables, the armor wires for vertical riser cable for indoor installation shall be in accordance with Table 7-22 for borehole cable, but with a tensile safety factor of not less than four. Wire band servings in accordance with 7.4.1.2 shall be applied.

7.5 DIVISION III

7.5.1 Buried Land Cables

Division III gives details of construction of round wire armor for sheathed and non-sheathed buried land cables requiring greater longitudinal strength than that provided by flat tape armor, but not the strength of the regular armor required for submarine service. The requirements of Division I pertaining to quality of materials, design, and construction apply also to these buried round wire armored cables except as set forth in the following sections.

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7.5.1.1 Armor

The size of armor wire and the thickness of a jute or equivalent bedding shall be in accordance with Table 7-27.

The length of lay of the armor wires shall be not less than three nor more than twelve times their pitch diameter. This lay shall be used such that the armor will be applied closely without appreciable space between wires.

A serving as specified in 7.3.7.2 shall be applied over the armor.

Table 7-27
THICKNESS OF BEDDING AND SIZE OF ARMOR WIRE

Calculated Diameter of Cable Under Bedding		Minimum Thickness of Bedding		Nominal Size of Armor Wire		
inches	mm	mils	mm	BWG	mils	mm
0 - 0.750	0 - 19.05	45	1.14	14	83	2.11
0.751 - 1.000	1 9.08 - 25.40	65	1.65	12	103	2.77
1.001 - 1.700	25.43 - 43.18	80	2.03	10	134	3.40
1.701 - 2.500	43.21 - 63.50	80	2.03	8	165	4.19
2.501 & larger *	63.53 & larger	95	2.41	6 *	203	5.16

* For cable diameters over 2.500 inches (63.50 mm) where greater strength is desired than is obtainable with the No. 6 BWG wires or where the required number of wires exceeds the capacity of the armoring machine, a No. 4 BWG (238 mils or 6.05 mm diameter) wire size may be used.

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Section 8
ASSEMBLY, FILLERS, AND CABLE IDENTIFICATION

8.1 ASSEMBLY OF MULTIPLE-CONDUCTOR CABLES

Multiple-conductor cables shall be assembled in accordance with Section 8 unless otherwise modified by Section 7.

8.1.1 Multiple-Conductor Cables

Multiple conductor cables shall be cabled with a left-hand lay. A left-hand lay is defined as a counterclockwise twist away from the observer.

With a Common Covering:
The length of lay of the individual conductors in a cable with a common covering shall not exceed the value calculated from the factor given in Table 8-1.

Without a Common Covering:
The length of lay of the individual conductors in a 2, 3, or 4 conductor cable without a common covering shall not exceed 60 times the largest conductor diameter. The largest conductor is the insulated conductor having the largest calculated overall diameter.

Table 8-1
CONDUCTOR MULTIPLYING FACTORS

Number of Conductors In Cable	Multiplying Factors Based On Calculated Diameter
2	30 times largest conductor
3	35 times largest conductor
4	40 times largest conductor
5 or more	15 times assembled cable diameter

8.2 FILLERS

Fillers shall be used in the interstices of multiple-conductor round cable with a common covering where necessary to give the completed cable a substantially circular cross section.

Fillers shall be of suitable material which is separate or integral with the jacket.

8.3 CONDUCTOR IDENTIFICATION

When required, insulated conductors shall be identified by any suitable means.

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8.4 CABLE IDENTIFICATION

The outer jacket surface of the cable shall be suitably marked throughout its length by surface and/or indent print, at a maximum interval of 1.0 meter with the following information:

Manufacturer's Identification or trade name
Size of Conductor
Conductor Material
Type of Insulation
Voltage Rating
Nominal Insulation Thickness (See Table 8-2)
Power Cable Symbol (Lightning Bolt) per the NESC* (Req'd for cables intended for direct buried applications only)
Year of Manufacture

*The power cable symbol shall be printed in accordance with the National Electrical Safety Code (NESC) Rule 350. The code requires the symbol to be indented or embossed in the cable jacket. Exception: Cables with jackets that cannot be effectively marked in accordance with Rule 350G need not be marked.

Table 8-2
NOMINAL INSULATION THICKNESS

Rated Circuit Voltage, Phase-to-Phase Voltage	Conductor Size, (AWG or kcmil)	Nominal Insulation Thickness (mils)	
		100 Percent Level	133 Percent Level
2001-5000	8-1000	90	90
	1001-3000	140	140
5001-8000	6-1000	115	140
	1001-3000	175	175
8001-15000	2-1000	175	220
	1001-3000	220	220
15001-25000	1-3000	260	320
25001-28000	1-3000	280	345
28001-35000	1/0-3000	345	420
35001-46000	4/0-3000	445	580

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Section 9
TESTING and TEST METHODS

9.1 GENERAL

9.1.1 Testing and Test Frequency

All wires and cables shall be tested at the factory as necessary to determine their compliance with the requirements given in Sections 2 through 8. When there is a conflict between the test methods given in Section 9 and publications of other organizations to which reference is made, the requirements of Section 9 shall apply.

This Standard does not require any specific frequencies for sampling (for test) of cable products or components. One program of sampling frequencies, based on the ICEA T-26-465/NEMA WC 54 guide, is suggested in Table 9-1.

Tests on samples shall be made on samples selected at random. Each test sample shall be taken from an accessible end of a coil or reel. Each coil or reel selected and the sample taken from it shall be identified. The lengths of samples and the numbers of specimens to be prepared from each sample shall be as specified under the individual tests.

If all of the samples pass any test specified in this Standard, the quantity of cable they represent shall be considered as meeting the requirements of this Standard with regard to that test. Failure of any sample shall not preclude resampling and retesting the length of cable from which the original sample was taken.

9.1.2 Test Methods

Not all of the tests described in Section 9 are applicable to every cable covered by this Standard, nor are all the tests that apply to cables covered in this Standard described in Section 9. Refer to the sections of this Standard that set forth the specific requirements for each material and type of cable to determine what tests are applicable to each type of cable.

Except where test and measurement methods are specifically detailed or modified by Section 9 of this Standard, the methods and procedures used to determine compliance with the requirements in Sections 2 through 8 are those applicable in the ICEA T-27-581/NEMA WC 53 guide or in the editions of other industry standards referenced in this Standard.

Table 9-1 lists tests which are conducted according to other standards. Where noted, one or more portions of Section 9 of this standard provide specific instructions which may alter, clarify, or supersede portions of the referenced standard.

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Table 9-1
TESTS CONDUCTED TO OTHER STANDARDS

Test	Referenced Standard	Additional Instructions In This Standard	Suggested Frequency per ICEA/NEMA T-26-465/ WC54*
Conductor DC Resistance	T-27-581		100%
Conductor Diameter Measurement	T-27-581	2.5	Plan F**
Thickness	T-27-581	9.2	T-27-581
Tensile, Elongation & Set	ASTM D 412	9.1.3	Plan A
Hot Creep	T-28-562		Plan D
Solvent Extraction	ASTM D 2765		ASTM D 2765
Heat Distortion (Deformation)	T-27-581	9.1.3	Plan A
Absorption Coefficient For PE	ASTM D 3349	9.1.3	Plan E
Cold Bend	T-27-581	9.8	Plan C
Flexibility of Armored Cable	T-27-581	9.9	Plan B
Electrical Accelerated Water Absorption (EM-60)	T-27-581	9.11	Plan E
ac Voltage Withstand	T-27-581	9.12.1	100%
Partial-Discharge Test	T-24-380	9.12.2	100%
Insulation Resistance	T-27-581	9.12.3	Plan E
Dielectric Constant & Dissipation Factor Test	T-27-581		Plan E
Environmental Stress Cracking	ASTM D 1693	9.1.3, 9.6	Plan E
Oil Immersion	ASTM D 471	9.4.2	Plan A
Sunlight Resistance Test	ASTM G 23 or G 26	9.7	Plan E
Cable Tray Flame Test	T-30-520	9.10	Plan E
Spark Test for Nonconducting Stress Control Layer	T-27-581	3.3.2	100%
Dry Electrical Test for EPR Class III Insulation	T-27-581	9.21	Plan E
Insulation Corona Discharge Resistance for Class IV EPR	T-27-581	9.16	Plan E
Jacket Spark Test	T-27-581	7.1.21	100%

* Unless otherwise noted.
** Plan F: One sample from each end of a manufacturer's master length or one sample from the outer end of each length is sufficient if at least one sample is taken every 10,000 ft. (3000m).

9.1.3 Number of Test Specimens from Samples

When a lot is sampled for a test listed below three test specimens are to be prepared from every sample selected for each test. One specimen from each sample shall be tested, except that the total number of specimens tested shall not be less than three. The average of the results of these tests is to be reported for the lot.

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Determination of unaged properties:
Tensile strength, tensile stress, and ultimate elongation
Permanent set
Accelerated aging tests:
Air oven aging
Oil immersion
Heat distortion (deformation)
Absorption coefficient
Environmental stress cracking

9.2 THICKNESS MEASUREMENTS

9.2.1 Beddings and Servings

The thickness of bedding or serving under armor shall be determined by the use of a diameter tape and shall be considered as one half of the difference between the measurements under and over the bedding or serving. The measurement in each case shall be the average of five readings taken at different points along the bedding or serving.

9.2.2 Other Components

Thickness of other components shall be determined in accordance with ICEA T-27-581/NEMA WC 53.

9.3 SAMPLES AND SPECIMENS FOR PHYSICAL AND AGING TESTS

9.3.1 General

Physical and aging tests shall be those required by Sections 3, 4, 5 and 6 of this Standard. No tests shall be performed on any jacket having a specified thickness of less than 30 mils (0.76 mm).

9.3.2 Sampling

9.3.2.1 Extrudable Conductor Stress Control Material

Material intended for extrusion shall be used to mold a sample large enough to yield at least three test specimens for the aged elongation test.

9.3.2.2 Insulations

Samples of cross-linked-insulated conductors for the unaged and aged physical tests shall be taken after curing of the insulation but prior to the application of all coverings except those applied over the insulation before it is cured or in the same process as the curing step. For insulation subjected to a second curing, samples of the insulated conductor may be taken either before or after the second curing.

9.3.2.3 Thermoplastic Jackets

Samples of thermoplastic-jacketed cables for the unaged and aged physical tests of the jacket shall be taken prior to the application of all coverings over the jacket except those applied in the same process as the application of the jacket.

9.3.2.4 Cross-linked Jackets

Samples of cross-linked-jacketed cables for the unaged and aged physical tests of the jacket shall be taken after curing but prior to the application of all coverings except those applied over the jacket before it is cured or those applied in the same process as the curing step.

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9.3.3 Size of Test Specimens

Unless otherwise allowed in this Section or otherwise called for in the instructions for a specific test, the test specimens shall be prepared using ASTM D412 Dies B, C, D or E from a sample whose length is not less than the length of the die used to cut the specimen. The length of all specimens prepared for each specific test shall be equal.

In the case of wire and cable smaller than size 6 AWG having a specified insulation thickness of 90 mils (2.29 mm), the insulation test specimen shall be permitted to be the entire cross-section of the insulation. When the full cross-section is used, the specimen shall not be cut longitudinally.

In the case of wire and cable size 6 AWG and larger, or in the case of wire and cable smaller than size 6 AWG having an insulation thickness greater than 90 mils (2.29 mm), insulation specimens approximately rectangular in section with a cross section not greater than 0.025 square inch (16 mm^2) shall be cut longitudinally from the insulation sample.

In extreme cases it may be necessary to use a sector-shaped test specimen cut longitudinally from the insulation sample.

Specimens for tests on jacket compounds shall be taken from the sample by cutting parallel to the axis of the wire or cable. The test specimen shall be a sector cut with a sharp knife or a shaped specimen cut out with a die, and shall have a cross-sectional area not greater than 0.025 square inch (16 mm^2) after irregularities, corrugations, and reinforcing cords or wires have been removed.

9.3.4 Specimens with Bonded Layers

If bonded layers cannot be separated, specimens shall be prepared by planing or buffing. In some instances it may be possible to prepare specimens of one layer by planing but necessary to prepare specimens of the other layer by buffing.

If planing is employed, strips of the combined materials shall be cut from the conductor so that acceptable specimens can be prepared from these strips in such a manner that material from only one layer is present in the region between the gauge marks.

If buffing is employed, the buffing apparatus for this operation shall be equipped with a cylindrical table arranged so that it can be advanced very gradually. The conductor shall be removed from a short length of wire by slitting the coverings. The length of combined materials shall be stretched into the clamps of the buffing apparatus so that it lies flat, with the layer to be removed toward the wheel. The layer to be removed shall be buffed off, with due care not to buff any further than necessary. If necessary, the process shall be repeated with another length of combined materials, except that the other layer shall be buffed off.

Die-cut specimens shall be prepared from the planed or buffed pieces after they have been allowed to recover for at least 30 minutes. (In the case of specimens from small wires, it may be necessary to use a die having a constricted portion 1/8 inch (3.18 mm) wide.

9.3.5 Specimen Surface Irregularities

Test specimens shall have no surface incisions and shall be as free as possible from other imperfections. Where necessary, surface irregularities, such as, corrugations due to stranding, etc., shall be removed so that each test specimen will be smooth and of uniform thickness.

9.3.6 Specimens for the Aging Tests

Test specimens of similar size and shape shall be prepared from each sample in accordance with the appropriate instructions in 9.3.2 through 9.3.5 Test specimens shall be prepared and tested identically to the unaged test specimens.

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Die-cut specimens shall be smoothed before being subjected to the aging tests wherever the thickness of the specimen is 90 mils (2.29 mm) or greater before smoothing.

The dimensions of the specimen to be aged shall be determined before aging.

Specimens shall not be heated, immersed in water, nor subjected to any mechanical or chemical treatment not specifically described in this Standard. Specimens for aging tests having cable tape applied prior to curing shall be aged with the tape removed.

Simultaneous aging of different compounds should be avoided. For example, high-sulfur compounds should not be aged with low-sulfur compounds, and those containing antioxidants should not be aged with those containing no antioxidant. Some migration is known to occur.

The test specimens shall be suspended vertically in such a manner that they are not in contact with each other or the sides of the chamber.

Unless otherwise specified in the specific aging tests the aged specimens shall have a rest period of not less than 16 hours nor more than 96 hours between the completion of the aging tests and the determination of physical properties. Physical tests on both the aged and unaged specimens shall be made at approximately the same time.

9.3.7 Calculation of Area of Test Specimens

9.3.7.1 Annular Specimens

Where the total cross-section of the insulation is used, the area shall be taken as the difference of the area of the circle whose diameter is the average outside diameter of the insulation and the cross-section of the conductor.

The cross-sectional area of a stranded conductor shall be calculated from its maximum diameter and shall include the areas between the strands. For this calculation, the area of the conductor also includes the cross-sectional area of any separator between the insulation and the conductor.

9.3.7.2 Thin Sections That Are Arcs of Annuli

When the specimen cross section is the thin outer portion of a sector of a circle, the area shall be calculated as the specimen thickness times the specimen width. This applies either to a straight test piece or to one stamped out with a die, and it assumes corrugations have been removed.

9.3.7.3 Thick Specimens that are Arcs of Annuli

When the specimen cross section is the thick outer portion of a sector of a circle, the area shall be calculated as the proportional part of the area of the total insulation cross-section.

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9.3.7.4 Specimens that are Segments of Circles

When a slice cut from the insulation by a knife or plane moved parallel to the wire is used and when the cross section of the slice is the cross section of a segment of a circle, the area ***A*** shall be calculated as that of the segment of a circle whose diameter ***D*** is the insulated conductor diameter. The height ***H*** of the segment is the thickness along the center-line of the specimen.
The area is calculated as:

$$A = 0.25(D^2)\cos^{-1}\left[\frac{D-2H}{D}\right] - 0.5(D-2H)\sqrt{DH-H^2}$$

In lieu of calculation, the value may be obtained from a table giving the areas of a unit circle for the ratio of the height of the segment to the diameter of the circle.

9.3.7.5 Irregular Specimens

When the cross section of the specimen is irregular, the area shall be calculated from a direct measurement of the specimen volume or from the specific gravity and the weight of a known length of the specimen having a uniform cross section.

9.4 AGING TESTS

9.4.1 Air Oven Aging Test

The test specimens shall be heated at the required temperature for the specified period in an oven having forced circulation of fresh air. The oven temperature shall be controlled to ± 1°C and recorded.

9.4.2 Oil Immersion Test

The test specimens shall be completely immersed in ASTM Oil No. 2, described in Table I of ASTM D471, or in IRM 902 oil, at the specified temperature for the specified time period. The specimens shall then be removed from the oil, blotted lightly to remove excess oil, and preconditioned under the following conditions prior to testing for tensile strength and elongation:

Thermoset specimens: suspended in air at room temperature for 4 hr ± 0.5 hr.
Thermoplastic specimens: allowed to rest at room temperature for a period of 16 hr to 96 hr.

The calculation for tensile strength shall be based on the cross-sectional area of the specimen obtained before immersion in oil. Likewise, the elongation shall be based on the gauge marks applied to the specimen before immersion in the oil.

9.5 HEAT SHOCK TEST

A sample of PVC jacketed cable shall be wound tightly for the specified number of turns around a mandrel having a diameter in accordance with Table 9-2, held firmly in place, and subjected to the specified temperature for 1 hr. At the end of the test period, the sample shall be examined for cracking of the insulation or jacket that is visible under 1x magnification.

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Table 9-2
MANDREL DIAMETER FOR HEAT SHOCK TEST

Outside Diameter of Wire or Cable inches	Outside Diameter of Wire or Cable mm	Number of Adjacent Turns	Mandrel Diameter As A Multiple of Wire or Cable Outside Diameter
0.750 or less	0 - 19.05	six 360° turns	3
0.751 - 1.500	19.08 - 38.10	one 180° bend	8
1.501 & larger	38.13 & larger	one 180° bend	12

9.6 ENVIRONMENTAL STRESS CRACKING TEST

Except as otherwise specified in this Section, this test shall be performed in accordance with ASTM D1693. Use Condition A for LDPE and for LLDPE (ASTM D1248 Type I). Use Condition B for MDPE and HDPE (ASTM Types II, III & IV). Conditions A and B are defined in ASTM D1693.

The test specimens shall be molded from material taken from the completed cable. The number of specimens shall be as specified in paragraph 9.1.3.

The cracking agent shall be a full-strength solution Igepal CO-630 made by GAF Corporation, or its equivalent. The temperature chamber may be either a water bath or an oven, and it shall be controlled to 50°C ± 1°C.

9.7 SUNLIGHT RESISTANCE TEST

When this test is specified, (See 7.1.17.) five samples, each sufficiently large to produce two smaller samples, shall be prepared from material intended for extrusion or from completed cable. One of each smaller sample shall be subjected to the exposure cycles and the other shall serve as the comparative unexposed specimen.

The five samples for exposure shall be mounted vertically in the specimen drum of the carbon-arc-radiation and water-spray exposure equipment similar to the Type D apparatus in ASTM G 23 (or in the specimen rack of the xenon-arc-radiation and water-spray exposure equipment similar to Type B apparatus in ASTM G 26). The exposure time shall be 720 hours.

Following the exposure duration, one specimen shall be die-cut from each of the five exposed samples and from each of the unexposed samples. Each specimen shall be tested for tensile and elongation. The resulting test values of the five specimens of each group shall be averaged. The average tensile strength value and the average elongation value of the exposed samples shall be divided by the similarly respective average values of unexposed samples and converted to a percentage to determine the retention value.

9.8 COLD-BEND TEST

The cold bend test shall be performed in accordance with ICEA T-27-581/NEMA WC 53, using a mandrel of the diameter specified in Table 9-3.

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Table 9-3
MANDREL DIAMETER FOR COLD-BEND TEST

Cable Construction To Be Tested	Mandrel Diameter As A Multiple of Wire or Cable Outside Diameter
Insulated conductors without further covering	8
Jacketed conductors having an outside diameter of 0.800 in or less	8
Jacketed conductors having an outside diameter larger than 0.800 in	10

9.9 TIGHTNESS OF POLYETHYLENE JACKET TO SHEATH TEST

The extruded jacket shall be removed for 5 inches (127 mm) from each end of a 12-inch (305 mm) sample of cable, leaving a 2-inch (50.8 mm) ring intact and undisturbed at the center. The sample shall then be inserted vertically in a hole in a flat rigid plate which is at least 10 mils (0.254 mm) larger than the diameter over the sheath but not over 40 mils (1.02 mm) larger. The weight to be applied shall be equal to 10 lb (4.54 kg) per inch (25.4 mm) of outside diameter of the metallic sheath minus the weight of the prepared sample, rounded off to the nearer half pound (0.23 kg).

9.10 TRAY CABLE FLAME TEST (QUALIFICATION TEST)

When this test is specified, (See 7.1.18.) it shall be performed in accordance with ICEA T-30-520.

9.11 ACCELERATED WATER ABSORPTION TEST, ELECTRICAL METHOD AT 60HZ

(EM-60) (Qualification Test)

The Accelerated Water Absorption test shall be performed in accordance with ICEA T-27-581/NEMA WC-53

9.12 ELECTRICAL TESTS ON COMPLETED CABLES

9.12.1 Voltage Tests

9.12.1.1 General

These tests consist of voltage tests on each length of completed cable. The voltage shall be applied between the conductor and the metallic shield. The rate of increase from the initially applied voltage to the specified test voltage shall be approximately uniform and shall be not more than 100 percent in 10 seconds nor less than 100 percent in 60 seconds.

9.12.1.2 Cables With Metallic Sheath, Metallic Shield, or Metallic Armor

All cables shall be tested with the metallic sheath, shield or armor grounded, without immersion in water, at the test voltage specified. The test voltage shall be applied between the insulated conductor(s) and ground.

9.12.1.3 AC Voltage Test

This test shall be made with an alternating potential from a transformer and generator of ample capacity but in no case less than 5 kilovolt amperes. The frequency of the test voltage shall be nominally between 49 and 61 hertz and shall have a wave shape approximating a sine wave as closely as possible.

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The initially applied ac test voltage shall be not greater than the rated ac voltage of the cable under test. The duration of the ac voltage test shall be 5 minutes. (For Voltage Tests After Installation, see Appendix F.)

9.12.2 Partial-Discharge Test Procedure

Partial-discharge test shall be performed in accordance with ICEA Publication T-24-380. The manufacturer shall wait a minimum of seven days after the insulation extrusion process before the tests are performed. The seven day waiting period may be reduced by mutual agreement between the purchaser and manufacturer when effective de-gassing procedures are used.

9.12.3 Insulation Resistance Test

The insulation resistance shall be measured after the completed cable alternating-current voltage withstand test but before the direct-current voltage withstand test, if used. The measured insulation resistance shall be converted to a value of "MΩ-1000 ft at 15.6 °C" using the procedure detailed in ICEA T-27-581/NEMA WC 53.

The insulation resistance constant shall be determined in accordance with ICEA T-27-581/NEMA WC 53.

9.13 VOLUME RESISTIVITY

9.13.1 Conductor Shield (Stress Control)

The samples shall be cut in half longitudinally and the conductor removed. Four silver-painted electrodes shall be applied to the conductor stress control layer. The two potential electrodes shall be at least 2 inches (50.8 mm) apart. A current electrode shall be placed at least 1 inch (25.4 mm) beyond each potential electrode. When a high degree of accuracy is not required, this test may be made with only two electrodes spaced at least 2 inches (50.8 mm) apart.

The power of the test circuit shall not exceed 100 milliwatts. The test shall be made at the specified temperature with either ac or dc voltage.

The volume resistivity shall be calculated as follows:

$$\rho = \frac{R\,(D^2 - d^2)}{100\,L}$$

Where:

ρ = Volume resistivity in ohm-meters.
R = Measured resistance in ohms.
D = Diameter over the conductor stress control layer in inches.
d = Diameter over the conductor in inches.
L = Distance between potential electrodes in inches.

9.13.2 Insulation Shield

Four silver-painted annular-ring electrodes shall be applied to the surface of the insulation shield layer. The two potential electrodes shall be at least 2 inches (50.8 mm) apart. A current electrode shall be placed at least 1 inch (25.4 mm) beyond each potential electrode. Where a high degree of accuracy is not required, the test may be made with only two electrodes spaced at least 2 inches (50.8 mm) apart.

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The power of the test circuit shall not exceed 100 milliwatts. The test shall be made at the specified temperature with either ac or dc voltage.

The volume resistivity shall be calculated as follows:

$$\rho = \frac{2R\,(D^2 - d^2)}{100\,L}$$

Where:

ρ = Volume resistivity in ohm-meters.
R = Measured resistance in ohms.
D = Diameter over the insulation stress control layer in inches.
d = Diameter over the insulation in inches.
L = Distance between potential electrodes in inches.

9.14 ADHESION (INSULATION SHIELD REMOVABILITY TEST)

The stripping test shall be performed in accordance with ICEA T-27-581/NEMA WC-53 (Adhesion).

9.15 ABSORPTION COEFFICIENT

Test specimens shall be prepared from test samples selected in accordance with paragraph 9.1.3. The absorption coefficient of jacket compounds shall be determined in accordance with ASTM D 3349.

9.16 TESTS FOR DISCHARGE RESISTANT INSULATION

9.16.1 Discharge Resistance Test for EPR Class IV Insulation (Qualification Test)

Compound mixing qualification of the insulation used for discharge resistant cable designs is required. Once per month a sample of each qualified insulation shall be obtained from each compound mixing line and subjected to this test.

The test shall be performed in accordance with ASTM D 2275 using the following standard specimens and conditions.

9.16.1.1 Test Specimens

From each test sample, three test specimens each having a minimum diameter of 4 inches (101.6 mm) and a thickness of 0.060 inch ± 0.004 inch (1.52 mm ± 0.10 mm), shall be molded and suitably cured. The prepared specimens shall be held for a minimum of 72 hours at room temperature followed by 16 hours minimum in the same environment as the electrical discharge test.

9.16.1.2 Test Environment

The discharge test shall be performed in an area provided with a controlled-draft flow of conditioned air to maintain the required relative humidity and temperature and with suitable venting to remove ozone and other gasses.

9.16.1.3 Test Electrodes

The electrodes shall be of stainless steel Type 309 or 310, with a surface finish of 16 μinch (0.406 μm). Each upper electrode, to which the test voltage is applied, shall be a cylindrical rod having a diameter of 0.250 inch ± 0.010 inch (6.35 mm ± 0.254 mm) and a length adjusted to provide a contact weight of 30 grams ± 3 grams when positioned vertically atop the center of the insulation specimen. The contacting

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end shall be flat except for edges rounded to a radius of 0.035 inch ± 0.005 inch (0.89 mm ± 0.127 mm). The lower electrode(s) shall be electrically grounded and may be either (1) a common plate under, and extending at least 2 inches (50.8 mm) beyond, the array of upper electrodes or (2) individual flat discs of 1.25 inch (31.75 mm) minimum diameter, centered under each upper electrode.

9.17 METHOD FOR DETERMINING DIELECTRIC CONSTANT (S.I.C.) AND DIELECTRIC STRENGTH OF EXTRUDED NONCONDUCTING POLYMERIC STRESS CONTROL LAYERS

The test specimen shall be an 18 inch (45.7 mm) length of conductor over which 0.030 inch (0.76 mm) of nonconducting stress control material has been extruded.

The central 12 inch (30.5 mm) length shall be shielded using a silver-painted electrode or equivalent applied to the surface of the stress control material.

The capacity C, in picofarads, shall be measured at the required temperature using a suitable bridge and a 60 Hz potential. The specimen shall be held at the required temperature for at least 15 minutes prior to measurement.

The geometric capacitance C_0 in picofarads, shall be calculated for the 12 inch (30.5 mm) specimen as follows:

$$C_0 = \frac{7.354}{\log_{10}\left(\frac{D}{d}\right)}$$

Where: d = diameter over conductor
D = diameter over the nonconducting stress control layer

The ratio of measured capacitance divided by the geometric capacitance, C/C_o, shall be the Dielectric Constant (S.I.C.) of the stress control material.

Following the capacitance measurement and while the specimen is held at the required temperature, a 60 Hz ac potential shall be applied between the conductor and the grounded shield (painted electrode) with an increasing rate of rise not in excess of 100 volts per second until dielectric failure occurs. The dielectric withstand stress, in volts per mil* shall be calculated as follows:

$$S = \frac{2V}{(D-d)1000}$$

Where: D and d in inches
V in volts, actual breakdown level
*S (V/mil) may be expressed as MV/m by dividing by 25.4**.**

9.18 HOT CREEP TEST

The Hot Creep Test shall be determined in accordance with ICEA Publication T-28-562.

9.19 WAFER BOIL TEST FOR EXTRUDED THERMOSET SHIELDS

Any outer covering and the conductor shall be removed. A representative cross section containing the extruded conductor shield and insulation shield, shall be cut from the cable. The resulting wafer shall be at least 25 mils (0.64 mm) thick. The wafer may be further separated into concentric rings by careful

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separation of the shield from the insulation. This may include the use of a punch to separate the conductor shield or insulation shield from most of the insulation.

The resulting wafer(s) or rings shall then be immersed in boiling decahydronaphthalene with 1 percent by weight Antioxidant 2246 (or other reagents specified in ASTM D 2765, such as xylene) for 5 hours using the equipment specified in ASTM D 2765. (This solution may be reused for subsequent tests provided that it works as effectively as a fresh solution). The wafer(s) shall then be removed from the solvent and examined for shield/insulation interface continuity with a minimum 15-power magnification.

Total or partial separation of the semiconducting shields from the insulation is permissible. Partial loss of the shields is also permissible provided each shield is a continuous ring. If the conductor shield dissolves or cracks such that it does not maintain a continuous ring, the cable lot shall be rejected. If the insulation shield dissolves or cracks such that it does not maintain a continuous ring, the cable lot shall either be rejected by the manufacturer or a sample of insulation shield from the same lot shall be subjected to the requirements of 9.22 as a referee test.

9.19.1 Insulation Shield Hot Creep Properties

Hot creep and set properties shall be determined at 150°C ± 2°C in accordance with ICEA T-28-562 with the sample removed from the cable core. The degree of cross-linking shall be adequate to limit elongation and set to the values in Table 9-4.

Table 9-4
INSULATION SHIELD HOT CREEP REQUIREMENTS

Physical Requirements	Extruded Insulation Shield
Maximum elongation	100%
Maximum set	5%

9.20 MOISTURE CONTENT

Each end of each shipping length shall be examined for moisture under the jacket (if the cable is jacketed) and for moisture in the conductor (if cable does not have a sealant and is stranded).

9.20.1 Moisture Under the Jacket

If the cable is jacketed, 6 inches (150 mm) of the jacket shall be removed and the area under the jacket shall be visually examined for the presence of moisture. If water is present, or there is an indication that it was in contact with moisture, effective steps shall be taken to assure that the moisture is removed or that the length of cable containing moisture under the jacket is discarded.

9.20.2 Moisture in the Conductor

If the cable has an unsealed, stranded conductor, 6 inches (150 mm) of the conductor shall be exposed on each end. The strands shall be individually separated and visually examined. If water is present, the conductor shall be subjected to 9.20.4.

9.20.3 Water Expulsion Procedure

A suitable method of expelling water from the strands shall be used until the cable passes the Presence of Water Test. As soon as possible after the procedure, both ends of the cable shall be sealed to prevent the ingress of water during shipment and storage.

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9.20.4 Presence of Water Test

To verify the presence of moisture in the conductor, the following steps shall be taken.

Each length of cable to be tested shall be sealed at one end over the insulation shield using a rubber cap filled with anhydrous calcium sulphate granules. The rubber cap shall be fitted with a valve.

Dry nitrogen gas or dry air shall be applied at the other end until the pressure is 15 psi (100 kPa) gauge.

After 15 minutes, a check of the change of color of the granules in the rubber cap shall be made.

If the color has not completely changed to pink after 15 minutes, it is an indication that a tolerable amount of moisture is present in the strands. In the case of complete change in color of all granules, the water shall be expelled from the conductor per 9.20.3.

This procedure shall be repeated after placing new granules in the cap.

9.21 DRY ELECTRICAL TEST FOR EPR CLASS III INSULATION ONLY

9.21.1 Test Samples

At least three samples shall be tested. A sample shall consist of a 1/0 AWG Aluminum or Copper 15kV cable utilizing a 100% insulation level wall thickness in accordance with Table 4-1 along with a conductor shield and an outer insulation shield with any suitable metallic shield. The samples shall be 30 feet (9.1 m) long.

9.21.2 Test Procedure

The test shall be performed with the sample cable in a 3 inch (76.2 mm) plastic pipe. The effective length between terminals shall be at least 20 feet (6.1 m). The sample shall be current loaded at 140ºC at rated phase-to-ground voltage for three weeks continuously. The current loading may be interrupted, if necessary, provided the total time is achieved.

9.21.3 Electrical Measurements

The capacitance and dissipation factor shall be measured initially at room temperature, 105ºC and 140ºC. After the test has been completed, the same properties shall be measured at the three temperatures. The dissipation factor shall not increase by more than 10% at each of the three test temperatures.

The partial discharge shall be measured on the initial specimens and after the current loading test has been completed. The value shall meet the limits in Part 4 of this standard and shall be reported. If limits are exceeded, the test shall be terminated and the cable design rejected.

9.22 RETESTS

9.22.1 Physical and Aging Properties and Thickness

If any test specimen fails to meet the requirements of any test, either before or after aging, that test shall be repeated on two additional specimens taken from the same sample. Failure of either of the additional specimens shall indicate failure of the sample to conform to this standard.

If the thickness or the diameter of an insulation or of a jacket of any reel is found to be less than the specified limits, that reel shall be considered as not conforming to this standard, and the measurement in question shall be made on each of the remaining reels.

Diameter measurements, when specified, should be made with the use of a diameter tape accurate to 0.01 inches (0.25 mm). When there are questions regarding compliance, measurements shall be made

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with an optical measuring device or with calipers with a resolution of 0.0005 inch (0.013 mm) and accurate to 0.001 inch (0.025 mm). At any given cross-section, the maximum diameter, minimum diameter, and two additional diameters which bisect the two angles formed by the maximum and minimum diameters shall be measured. The diameter for the cross-section shall be the average of the four values. This average diameter value shall be used to determine if the cable meets the specified limits. Any diameter measurement shall be made on cable samples that contain the conductor.

When ten or more samples are selected from any single lot, all reels shall be considered as not conforming to this standard if more than 10 % of the samples fail to meet the requirements for physical and aging properties and thickness. If 10 % or less fail, each reel shall be tested and shall be judged upon the results of such individual tests. Where the number of samples selected in any single lot is less than ten, all reels shall be considered as not conforming to this standard if more than 20 % of the samples fail. If 20 % or less fail, each reel, or length shall be tested and shall be judged upon the results of such individual tests.

9.22.2 Other Tests

If any sample fails to pass any other test required by this Standard, resampling shall be carried out in accordance with ICEA T-26-465/NEMA WC 54.

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Section 10
CONSTRUCTIONS OF SPECIFIC TYPES

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Section 11
APPENDICES

Appendix A
NEMA, ICEA AND ASTM STANDARDS

A.1 NEMA PUBLICATIONS*

WC 26 (1993) *Wire & Cable Packaging*

WC 53/ICEA T-27-581 (1990)
Standard Test Methods for Extruded Dielectric Power, Control, Instrumentation & Portable Cables for Test

WC 54 (1990)/ICEA T-26-465
Guide for Frequency of Sampling Extruded Dielectric Power, Control, Instrumentation, and Portable Cables For Test

A.2 ICEA PUBLICATIONS*

P-32-382-1994 *Short Circuit Characteristics of Insulated Cable*

P-45-482-1994 *Short Circuit Performance of Metallic Shields and Sheaths on Insulated Cable*

T-24-380-1994 *Guide for Partial-Discharge Test Procedure*

T-25-425, (02/81) *Guide for Establishing Stability of Volume Resistivity for Conducting Polymeric Components of Power Cables*

T-28-562-1995 *Test Method for Measurement of Hot Creep of Polymeric Insulation*

T-31-610-1994 *Guide for Conducting a Longitudinal Water Penetration Resistance Test for Sealed Conductor*

T-32-645-1993 *Guide for Establishing Compatibility of Sealed Conductor Filler Compounds with Conductor Stress Control Materials*

P-79-561-1985 *Guide For Selecting Aerial Cable Messengers and Lashing Wires*

T-30-520-1986 *Guide For Conducting Vertical Tray Flame Test*

A.3 ASTM STANDARDS**

A90-95a *Test Method for Weight (Mass) of Coating on Iron & Steel Articles With Zinc or Zinc-Alloy Coatings*

B 3-95 *Soft or Annealed Copper Wire, Specification for*

B 5-89 *Tough-Pitch Electrolytic Copper Refinery Shapes, Specification for*

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B 8-95	*Concentric-Lay Stranded Copper Conductors, Hard, Medium-Hard, or Soft, Specification for*
B-29-92	*Pig Lead, Specification for*
B 33-94	*Tinned Soft or Annealed Copper Wire for Electrical Purposes, Specification for*
B 193-95	*Resistivity of Electrical Conductor Materials, Test for*
B 230-98	*Aluminum 1350-H19 Wire, for Electrical Purposes, Specification for*
B 231-95	*Concentric-Lay-Stranded Aluminum 1350 Conductors, Specification for*
B 233-97	*Aluminum 1350 Drawing Stock for Electrical Purposes, Specification for*
B 258-96	*Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors, Specification for*
B 263-94	*Determination of Cross-Sectional Area of Stranded Conductors, Method for*
B 400-94	*Compact-Round Concentric-Lay-Stranded Aluminum 1350 Conductors, Specification for*
B 496-92	*Compact Round Concentric-Lay Stranded Copper Conductors, Specification for*
B 609-97	*Aluminum 1350 Round Wire, Annealed And Intermediate Tempers, For Electrical Purposes, Specification For*
B 784-94	*Modified Concentric-Lay-Stranded Copper Conductor For Use In Insulated Electrical Cables, Specification For*
B 785-93	*Compact Round Modified Concentric-Lay-Stranded Copper Conductor For Use In Insulated Electrical Cables, Specification For*
B 786-93	*19 Wire Combination Unilay-Stranded Aluminum 1350 Conductors for Subsequent Insulation, Specification for*
B 787-93	*19 Wire Combination Unilay-Stranded Copper Conductors for Subsequent Insulation, Specification for*
B 800-94	*8000 Series Aluminum Alloy Wire for Electrical Purposes -Annealed and Intermediate Tempers, Specification for*
B 801-95	*Concentric-Lay-Stranded Conductors of 8000 Series Aluminum Alloy for Subsequent Covering or Insulation, Specification for*
B 835-93	*Compact Round SIW Stranded Copper Conductors, Specification for*
B 836-98	*Compact Round SIW Stranded Aluminum Conductors, Specification for*
D 412-98a	*Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers - Tension, Test Methods for*
D 470-97	*Crosslinked Insulations and Jackets for Wire & Cable, Test Methods for*

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D 471-98	*Rubber Property - Effect of Liquids, Test for*
D 746-79	*Brittleness Temperature of Plastics and Elastomers by Impact, Test Method for*
D1248-84 (89)	*Polyethylene Plastics Molding & Extrusion Materials, Specification for*
D 1693-98	*Environmental Stress - Cracking of Ethylene Plastics, Test Method for*
D 2275-89	*Voltage Endurance of Solid Insulating Materials Subjected to Partial Discharges (Corona) on the Surface, Test Method for*
D 2765-95	*Determination of Gel Content and Swell Ratio of Crosslinked Ethylene Plastics, Test Methods for*
D 3349-93	*Absorption Coefficient of Ethylene Polymer Material Pigmented with Carbon Black, Test Method for*
D 4496-87	*D-C Resistance or Conductance of Moderately Conductive Materials, Test Method of*
E 8-98	*Tension Testing of Metallic Materials, Test Methods for*
G 23-93	*Operating Light -Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials, Practice for*
G 26-96	*Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials, Practice for*

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Appendix B
EMERGENCY OVERLOADS

Operations at the emergency overload temperature of 130°C for insulations rated 90°C continuous and 140°C for insulations rated 105°C continuous shall not exceed 1500 hours cumulative during the lifetime of the cable.

Lower temperatures for emergency overload conditions may be required because of the type of material used in the cable, joints, and terminations or because of cable environmental conditions.

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APPENDIX C

PROCEDURE FOR DETERMINING DIMENSIONAL REQUIREMENTS OF JACKETS AND ASSOCIATED COVERINGS

C.1 Jacket, Bedding, Sheath, and Armor Thicknesses, Armor Wire Size, and Armor Metal Tape Width

Jacket, bedding, sheath, and armor thicknesses, armor wire size, and armor metal tape width shall be determined by calculating diameters as follows. This procedure is not intended for determining cable diameters.

C.1.1 The Calculated Diameter over the Shielded Single Conductor Core

The calculated diameter over the shielded single conductor core shall be determined as follows:

$$D_S = C + 2\,T + 90 \qquad \text{Eq. 1}$$

Where: D_S = Calculated diameter over the shielded single conductor core
C = Applicable Nominal conductor diameter from Section 2
T = Minimum point insulation thickness from Section 4

All dimensions are in mils

C.1.2 The Calculated Diameter over the Individual Conductor Jacket

The calculated diameter over the individual conductor jacket, for a multiple conductor cable having an overall covering, shall be determined as follows:

$$D_j = D_S + 2 \times \text{minimum Jacket thickness from Table 7-4} \qquad \text{Eq. 2}$$

C.1.3 The Calculated Diameter over the Assembly of Multiple Conductors

The calculated diameter over the assembly of multiple conductors shall be determined as follows:

Multiply the calculated diameter from C1.1 or C1.2, as applicable, by the appropriate multiplier as given below:

Number of Conductors	Multiplier
2	2.00
3	2.16
4	2.42

C.1.4 The Calculated Diameter over a Bedding Layer

The calculated diameter over a bedding layer shall be determined by adding the following adder to the calculated core diameter :

Adder = twice the bedding thickness specified Table 7-18

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C.1.5 The Calculated Diameter over Flat Metal Armoring Tapes

The calculated diameter over flat metal armoring tapes shall be determined by adding the following adder to the calculated diameter over the underlying core:

Tape Thickness – mils	Adder - mils
20	100
30	140

C.1.6 The Calculated Diameter over an Interlocking or Corrugated Armor

The calculated diameter over an interlocking or corrugated armor shall be determined by adding the following to the calculated diameter over the underlying core:

Armor Tape Thickness - mils	Adder - mils
15-20	150
21-25	165
26-30	190
31-34	220
35-40	250
41-49	260
50-55	270

C.1.7 The Calculated Diameter over a Smooth Sheath

The calculated diameter over a smooth sheath shall be determined by adding the following to the calculated diameter over the underlying core:

Adder = twice the thickness specified in Table 7-5, 7-6 or 7-7, as applicable.

C.1.8 The Calculated Diameter over a Steel Armor Wire

The calculated diameter over a steel armor wire shall be determined by adding the following to the calculated diameter over the underlying core :

Adder = twice the wire diameter specified in Table 7-16, 7-22, 7-24 or 7-25, as applicable.

C.2 Example Calculation

3/C 4/0 compressed (Class B) stranded conductor with extruded conductor shield and insulation shield, 15kV class cable with a 133% level insulation wall thickness, and 5 mil copper tape shield, jacketed singles, binder tape, galvanized steel interlocked armor, overall PVC jacket.

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Calculate the diameter over a 5 mil copper shielding tape:

C	512	mils
2T	420	mils (T = 210 from Section 4)
Adder	90	
Sub Total	1022	mils

Determine individual jacket thickness, for shielded single:

From Table 7-4 jacket thickness is 45 mils

Calculate diameter over individual jacket:

From above	=	1022 mils over copper tape shield
Plus	=	2 x 45 mils from Table 7-4
		1112 mils calculated diameter over individual jacket

Calculate the diameter over the three tape shielded jacketed conductors:

From above	=	1112	mils diameter over individual jacket
Times multiplier	=	x 2.16	from C.1.3 above
Sub Total	=	2402	mils calculated diameter over cabled conductors

Determination of galvanized steel tape width and thickness:

Based on the calculated diameter over the cabled conductors of 2.402 inches, the tape width, per Table 7-10, is 1.000 inch and the tape thickness, per Table 7-11, is 25 mils.

Calculate the diameter over the galvanized steel interlocking armor:

From above	= 2402	mils calculated diameter over cabled conductors
Plus adder	= 165	mils adder from C.1.6
Sub Total	=2567	mils calculated diameter over galvanized steel armor

Determination of overall jacket thickness:

Based on the calculated diameter over the interlocked armor of 2.567 inches, the jacket thickness, per Table 7-21, is 60 mils.

NOTE—Cable binder tapes are not considered when determining dimensional requirements of jackets and associated coverings.

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Appendix D
OPTIONAL FACTORY DC TEST

A factory dc voltage test may be performed with prior agreement between the manufacturer and the purchaser.

The equipment for the dc voltage test shall consist of a battery, generator or suitable rectifying equipment and shall be of ample capacity. The initially applied dc voltage shall be not greater than 3.0 times the rated ac voltage of the cable. The duration of the dc voltage test shall be 15 minutes.

Table D-1
DC TEST VOLTAGES

Rated Circuit Voltage, Phase-to-Phase Voltage	Conductor Size, (AWG or kcmil)	Insulation Level (Mils)				d-c Test Voltage, kV	
		100 Percent		133 Percent		100 Percent Insulation Level	133 Percent Insulation Level
		Minimum	Maximum	Minimum	Maximum		
2001-5000	8-1000	85	120	85	120	35	35
	1001-3000	135	170	135	170	35	45
5001-8000	6-1000	110	145	135	170	45	55
	1001-3000	165	205	165	205	45	55
8001-15000	2-1000	165	205	210	250	70	80
	1001-3000	210	250	210	250	70	80
15001-25000	1-3000	245	290	305	350	100	120
25001-28000	1-3000	265	310	330	375	105	125
28001-35000	1/0-3000	330	375	400	450	125	155
35001-46000	4/0-3000	425	485	550	610	165	215

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APPENDIX E
REPRESENTATIVE TENSILE STRENGTH AND ELONGATION OF NONMAGNETIC METALS

Metal	Tensile Strength		Elongation in a 2 in (50.8 mm) length, Percent
	psi	MPa	
Aluminum	13000-45000	90-310	15-45
Cupro-Nickel	50000-70000	345-482	20-40
Low Brass	40000-50000	276-345	40-50
Commercial Bronze	35000-42000	241-289	40
Copper	35000-50000	241-345	1-35
Monel	75000	517	45
Stainless	82000-90000	565-620	50
Zinc	20000	138	60

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APPENDIX F
VOLTAGE TESTS AFTER INSTALLATION

If voltage tests are made after installation, they shall be made immediately. The test voltage shall be a dc voltage as given in Table F-1. The voltage shall be applied between the conductor and the metallic shield with the shield and all other metallic components of the cable grounded. The rate of increase from the initially applied voltage to the specified test voltage shall be approximately uniform and shall be not more than 100 percent in 10 seconds nor less than 100 percent in 60 seconds.

The equipment for the dc voltage test shall consist of a battery, generator, or suitable rectifying equipment and shall be of ample capacity.

The initially applied dc voltage shall be not greater than 3.0 times the rated ac voltage of the cable.

The duration of the dc voltage test shall be 15 minutes.

Table F-1
DC TEST VOLTAGES AFTER INSTALLATION

Rated Circuit Voltage, Phase-to-Phase Voltage	Conductor Size, (AWG or kcmil)	Maximum dc Field Test Voltage - kV	
		100 Percent Insulation Level	133 Percent Insulation Level
2001-5000	8-1000	28	28
	1001-3000	28	36
5001-8000	6-1000	36	44
	1001-3000	36	44
8001-15000	2-1000	56	64
	1001-3000	56	64
15001-25000	1-3000	80	96
25001-28000	1-3000	84	100
28001-35000	1/0-3000	100	124
35001-46000	4/0-3000	132	172

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Appendix G
SHIELDING

G.1.1 Definition of Shielding

Shielding of an electric power cable is the practice of confining the dielectric field of the cable to the insulation of the conductor or conductors. It is accomplished by means of a conductor stress control layer and an insulation shield.

G.2.1 Functions of Shielding

G.2.1.1 Conductor Stress Control Layer

A conductor stress control layer is employed to preclude excessive voltage stress on voids between conductor and insulation. To be effective, it must adhere to or remain in intimate contact with the insulation under all conditions.

G.2.1.2 Insulation Shield

An insulation shield has a number of functions:

1. To confine the dielectric field within the cable.
2. To obtain symmetrical radial distribution of voltage stress within the dielectric, thereby minimizing the possibility of surface discharges by precluding excessive tangential and longitudinal stresses.
3. To protect cable connected to overhead lines or otherwise subject to induced potentials.
4. To limit radio interference.
5. To reduce the hazard of shock. This advantage is obtained only if the shield is grounded. If not grounded, the hazard of shock may be increased.

G.3.1 Use Of Insulation Shielding

G.3.1.1 Consideration of Installation and Operating Conditions

The use of shielding involves consideration of installation and operating conditions. Definite rules cannot be established on a practical basis for all cases, but the following features should be considered as a working basis for the use of shielding.

G.3.1.2 Where there is No Metallic Covering or Shield over the Insulation

Where there is no metallic covering or shield over the insulation, the electric field will be partly in the insulation and partly in whatever lies between the insulation and ground. The external field, if sufficiently intense in air, will generate surface discharge and convert atmospheric oxygen into ozone, which may be destructive to insulations and to protective jackets. If the surface of the cable is separated from ground by a thin layer of air and the air gap is subjected to a voltage stress that exceeds the dielectric strength of air, a discharge will occur, causing ozone formation.

G.3.1.3 The Ground

The ground may be either a metallic conduit, a damp nonmetallic conduit, or a metallic binding tape or rings on an aerial cable, a loose metallic sheath, etc. Likewise, damage to nonshielded cable may result when the surface of the cable is moist or covered with soot, soapy grease or other conducting film and the external field is partly confined by such conducting film so that the charging current is carried by the film to some spot where it can discharge to ground. The resultant intensity of discharge may be sufficient to cause burning of the insulation or jacket.

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G.3.1.4 Where Nonshielded Cables are Used

Where nonshielded cables are used in underground ducts containing several circuits that must be worked on independently, the external field, if sufficiently intense, can cause shocks to those who handle or contact energized cable. In cases of this kind, it may be advisable to use shielded cable. Shielding used to reduce hazards of shock should have a resistance low enough to operate protective equipment in case of fault. In some cases, the efficiency of protective equipment may require proper size ground wires as a supplement to shielding. The same considerations apply to exposed installations where cables may be handled by personnel who may not be acquainted with the hazards involved.

G.4.1 Grounding of the Insulation Shield

G.4.1.1 The Insulation Shield Must Be Grounded at Least at One End

The insulation shield must be grounded at least at one end and preferably at two or more locations. It is recommended that the shield be grounded at cable terminations and at splices and taps. Stress cones should be made at all shield terminations.

G.4.1.2 The Shield Should Operate at or Near Ground Potential

The shield should operate at or near ground potential at all times. Frequent grounding of shields reduces the possibility of open sections on nonmetallic covered cable. Multiple grounding of shields is desirable in order to improve the reliability and safety of the circuit. All grounding connections should be made to the shield in such a way as to provide a permanent low resistance bond. Shielding that does not have adequate ground connection due to discontinuity of the shield or to improper termination may be more dangerous than nonshielded nonmetallic cable and hazardous to life.

G.5.1 Shield Materials

G.5.1.1 Two Distinct Types of Materials

Two distinct types of materials are employed in constructing cable shields.

G.5.1.1.1 Conducting Tape or an Extruded Layer of Conducting Compound

Nonmetallic shields may consist of a conducting tape or an extruded layer of conducting compound. The tape may be conducting compound, fibrous tape faced or filled with conducting compound or conducting fibrous tape.

G.5.1.1.2 Tape, Braid, Concentric Serving of Wires, or a Sheath

Metallic shields should be nonmagnetic and may consist of tape, braid, concentric serving of wires, or a sheath.

G.6.1 Splices and Terminations

To prevent excessive leakage current and flashover, metallic and nonmetallic insulation shields, including any conducting residue on the insulation surface, must be removed completely at splices and terminations.

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Appendix H
ADDITIONAL CONDUCTOR INFORMATION

Table H-1
SOLID ALUMINUM AND COPPER CONDUCTORS

Conductor Size, AWG or kcmil	Approximate Weight			
	Aluminum		Copper	
	Pounds per 1000 Feet	kg/km	Pounds per 1000 Feet	kg/km
22	...	...	1.94	2.88
20	...	...	3.10	4.61
19	...	...	3.90	5.81
18	...	...	4.92	7.32
17	...	...	6.21	9.24
16	...	...	7.81	11.6
15	...	...	9.87	14.7
14	...	...	12.4	18.5
13	...	...	15.7	23.4
12	6.01	8.94	19.8	29.4
11	7.57	11.3	24.9	37.1
10	9.56	14.22	31.43	46.77
9	12.04	17.92	39.62	58.95
8	15.20	22.62	49.98	74.38
7	19.16	28.52	63.03	93.80
6	24.15	35.94	79.44	118.2
5	30.45	45.32	100.2	149.0
4	38.41	57.17	126.3	188.0
3	48.43	72.08	159.3	237.1
2	61.07	90.89	200.9	298.9
1	77.03	114.6	253.3	377.0
1/0	97.15	144.6	319.5	475.5
2/0	122.5	182.3	402.8	599.5
3/0	154.4	229.8	507.8	755.8
4/0	194.7	289.8	640.5	953.2
250	230.1	342.4	...	...
300	276.1	410.9	...	...
350	322.1	479.4	...	...
400	368.2	547.9	...	...
450	414.4	616.3	...	...
500	460.2	648.8	...	...

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Table H-2
CONCENTRIC STRANDED CLASS B ALUMINUM AND COPPER CONDUCTORS

Conductor Size		Approximate Diameter of Each Strand		Approximate Weight			
				Aluminum		Copper	
AWG or kcmil	Number of Strands	mils	mm	Pounds per 1000 Feet	kg/km	Pounds per 1000 Feet	kg/km
22	7	9.6	0.244	...	...	1.992	2.963
20	7	12.1	0.307	...	...	3.164	4.708
19	7	13.6	0.345	...	...	3.997	5.947
18	7	15.2	0.386	...	...	4.993	7.429
17	7	17.1	0.434	...	...	6.320	9.402
16	7	19.2	0.488	...	...	7.967	11.85
15	7	21.6	0.549	...	...	10.08	15.00
14	7	24.2	0.615	...	...	12.66	18.83
13	7	27.2	0.691	...	...	15.99	23.79
12	7	30.5	0.775	6.103	9.081	20.10	29.91
11	7	34.3	0.871	7.719	11.48	25.43	37.83
10	7	38.5	0.978	9.725	14.47	32.04	47.66
9	7	43.2	1.10	12.24	18.22	40.33	60.01
8	7	48.6	1.23	15.50	23.06	51.05	75.95
7	7	54.5	1.38	19.49	28.99	64.19	95.51
6	7	61.2	1.55	24.57	36.56	80.95	120.4
5	7	68.8	1.75	31.06	46.21	102.3	152.2
4	7	77.2	1.96	39.10	58.18	128.8	191.6
3	7	86.7	2.20	49.32	73.38	162.5	241.7
2	7	97.4	2.47	62.24	92.60	205.0	305.0
1	19	66.4	1.69	78.52	116.8	258.6	384.8
1/0	19	74.6	1.89	99.11	147.5	326.5	485.7
2/0	19	83.7	2.13	124.8	185.6	411.0	611.4
3/0	19	94.0	2.39	157.4	234.1	518.3	771.2
4/0	19	105.5	2.68	198.2	294.9	652.9	971.4
250	37	82.2	2.09	234.3	348.6	771.9	1148
300	37	90.0	2.29	280.9	417.9	925.3	1377
350	37	97.3	2.47	328.3	488.5	1082	1609
400	37	104.0	2.64	375.1	558.1	1236	1838
450	37	110.3	2.80	421.9	627.7	1390	2068
500	37	116.2	2.95	468.3	696.7	1542	2295
550	61	95.0	2.41	516.0	767.7	1700	2529
600	61	99.2	2.52	562.6	837.1	1853	2757
650	61	103.2	2.62	608.9	906.0	2006	2984
700	61	107.1	2.72	655.8	975.7	2160	3214
750	61	110.9	2.82	703.2	1046	2316	3446
800	61	114.5	2.91	749.6	1115	2469	3674
900	61	121.5	3.09	844.0	1256	2780	4136
1000	61	128.0	3.25	936.8	1394	3086	4591
1100	91	109.9	2.79	1030	1533	3393	5049
1200	91	114.8	2.92	1124	1672	3703	5509
1250	91	117.2	2.98	1172	1743	3859	5742
1300	91	119.5	3.04	1218	1812	4012	5969
1400	91	124.0	3.15	1311	1951	4320	6427
1500	91	128.4	3.26	1406	2092	4632	6892
1600	127	112.2	2.85	1499	2229	4936	7344
1700	127	115.7	2.94	1593	2371	5249	7809
1750	127	117.4	2.98	1641	2441	5404	8041
1800	127	119.1	3.03	1689	2512	5562	8275
1900	127	122.3	3.11	1780	2649	5865	8726
2000	127	125.5	3.19	1875	2789	6176	9188

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Table H-3
CONCENTRIC STRANDED CLASS C AND D ALUMINUM AND COPPER CONDUCTORS

Conductor Size, AWG or kcmil	Class C			Class D		
	Number of Strands	Approximate Diameter of Each Strand		Number of Strands	Approximate Diameter of Each Strand	
		mils	mm		mils	mm
14	19	14.7	0.373	37	10.5	0.267
13	19	16.5	0.419	37	11.8	0.300
12	19	18.5	0.470	37	13.3	0.338
11	19	20.8	0.528	37	14.9	0.378
10	19	23.4	0.594	37	16.7	0.424
9	19	26.2	0.665	37	18.8	0.478
8	19	29.5	0.749	37	21.1	0.536
7	19	33.1	0.841	37	23.7	0.602
6	19	37.2	0.945	37	26.6	0.676
5	19	41.7	1.06	37	29.9	0.759
4	19	46.9	1.19	37	33.6	0.853
3	19	52.6	1.34	37	37.7	0.958
2	19	59.1	1.50	37	42.4	1.08
1	37	47.6	1.21	61	37.0	0.940
1/0	37	53.4	1.36	61	41.6	1.06
2/0	37	60.0	1.52	61	46.7	1.19
3/0	37	67.3	1.71	61	52.4	1.33
4/0	37	75.6	1.92	61	58.9	1.50
250	61	64.0	1.63	91	52.4	1.33
300	61	70.1	1.78	91	27.4	1.46
350	61	75.7	1.92	91	62.0	1.57
400	61	81.0	2.06	91	66.3	1.68
450	61	85.9	2.18	91	70.3	1.79
500	61	90.5	2.30	91	74.1	1.88
550	91	77.7	1.97	127	65.8	1.67
600	91	81.2	2.06	127	68.7	1.74
650	91	84.5	2.15	127	71.5	1.82
700	91	87.7	2.23	127	74.2	1.88
750	91	90.8	2.31	127	76.8	1.95
800	91	93.8	2.38	127	79.4	2.02
900	91	99.4	2.53	127	84.2	2.14
1000	91	104.8	2.66	127	88.7	2.25
1100	127	93.1	2.36	169	80.7	2.05
1200	127	97.2	2.47	169	84.3	2.14
1250	127	99.2	2.52	169	86.0	2.18
1300	127	101.2	2.57	169	87.7	2.23
1400	127	105.0	2.67	169	91.0	2.31
1500	127	108.7	2.76	169	94.2	2.39
1600	169	97.3	2.47	217	85.9	2.18
1700	169	100.3	2.55	217	88.5	2.25
1750	169	101.8	2.59	217	89.8	2.28
1800	169	103.2	2.62	217	91.1	2.31
1900	169	106.0	2.69	217	93.6	2.38
2000	169	108.8	2.76	217	96.0	2.44

NOTE—The weights of Class C & Class D conductors are the same as for the equivalent Class B conductor (see Table H-2).

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Appendix I
RECOMMENDED BENDING RADII FOR CABLES

I.1 Scope

This appendix contains the minimum values for the radii to which insulated cables may be bent for permanent training during installation. These limits do not apply to conduit bends, sheaves or other curved surfaces around which the cable may be pulled under tension while being installed. In all cases the minimum radii specified refers to the inner surface of the cable and not to the axis of the cable.

I.2 Interlocked Armored and Metallic Sheathed Cables

The minimum bending radius for interlocked armored cables smooth or corrugated aluminum sheath or lead sheath shall be in accordance with Table I-1.

I.2.1 Flat Tape Armored or Wire Armored Cables

The minimum bending radius for all flat tape armored and all wire armored cables is twelve times the overall diameter of cable.

I.2.2 Shielded Cables, Without Armor

I.2.2.1 Tape Shielded Cables

The minimum bending radius for tape shielded cables given below applies to helically applied flat or corrugated tape or longitudinally applied corrugated tape shielded cables.

The minimum bending radius for a single conductor cable is twelve times the overall diameter.

For multiple-conductor or multiplexed single conductor cables having individually taped shielded conductors, the minimum bending radius is twelve times the diameter of the individual conductors or seven times the overall diameter, whichever is greater.

For multiple-conductor cables having an overall tape shield over the assembly, the minimum bending radius is twelve times the overall diameter of the cable.

I.2.2.2 Wire Shielded Cables

The minimum bending radius for a single conductor cable is eight times the overall diameter.

For multiple-conductor or multiplexed single conductor cables having wire shielded individual conductors, the minimum bending radius is eight times the diameter of the individual conductors or five times the overall diameter, whichever is greater.

For multiple-conductor cables having a wire shield over the assembly, the minimum bending radius is eight times the overall diameter of the cable.

I.3 Drum Diameters Of Reels

See NEMA Pub. No. WC26-1993, Wire and Cable Packaging, which is quoted in Table I-2.

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Table I1
MINIMUM RADII FOR POWER CABLE
SINGLE & MULTIPLE CONDUCTOR CABLES WITH INTERLOCKED ARMOR, SMOOTH OR CORRUGATED ALUMINUM SHEATH OR LEAD SHEATH

	Overall Diameter of Cable					
	inches 0.75 & less	mm 190 & less	inches 0.76 to 1.50	mm 191 to 381	inches 1.51 & larger	mm 382 & larger
	Minimum Bending Radius as a Multiple of Cable Diameter					
Smooth Aluminum Sheath Single Conductor Nonshielded, Multiple Conductor or Multiplexed, with Individually Shielded Conductors	10		12		15	
Single Conductor Shielded	12		12		15	
Multiple Conductor or Multiplexed, with Overall Shield	12		12		15	
Interlocked Armor or Corrugated Aluminum Sheath Nonshielded	7		7		7	
Multiple Conductor with Individually Shielded Conductor	12/7*		12/7*		12/7*	
Multiple Conductor with Overall Shield	12		12		12	
Lead Sheath	12		12		12	

* 12 x individual shielded conductor diameter, or 7 x overall cable diameter, whichever is the greater.

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Table I-2
EXCERPT FROM NEMA STANDARDS PUBLICATION WC 26-1993, WIRE AND CABLE PACKAGING

Type of Cable	Minimum Drum Diameter as a Multiple of Outside Diameter** of Cable
A. Single- and multiple-conductor nonmetallic-covered cable	
1. Nonshielded and wire shielded, including cables with concentric wires	
a. 0-2000 Volts	10
b. More than 2000 Volts	
1. Nonjacketed with concentric wires	14
2. All others	12
2. Tape Shielded	14
B. Single- and multiple-conductor metallic-covered cable	
1. Tubular metallic sheathed	
a. Lead	14
b. Aluminum	
1. Outside diameter-1.750" and less	25
2. Outside diameter-1.751" and larger	30
2. Wire armored	16
3. Flat tape armored	16
4. Corrugated metallic sheathed	
14	
5. Interlocked armor	14
C. Multiple single conductors cabled together without common covering, including self-supporting cables. The circumscribing overall diameter shall be multiplied by the factor given in item A or B and then by the reduction factor of 0.75.	
D. Combinations—For combinations of the types described in items A, B, and C, the highest factor for any component type shall be used.	
E. Single- and multiple-conductor cable in coilable nonmetallic duct	
Outside diameter of duct, inches-0.0-0.5026	26
0.51-1.0024	24
1.01-1.2522	22
1.26-1.5021	21
More than 1.5021	20

**Outside Diameter

1. When metallic-sheathed cables are covered only by a thermosetting or thermoplastic jacket, the "outside diameter" is the diameter over the metallic sheath itself. In all other cases, the outside diameter is the diameter outside of all the material on the cable in the state in which it is to be wound upon the reel.

2. For "flat-twin" cables (where the cable is placed upon the reel with its flat side against the drum), the minor outside diameter shall be multiplied by the appropriate factor to determine the minimum drum diameter.

3. The multiplying factors given for item E refer to the outside diameter of the duct.

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