This article is intended to familiarize the reader with types of cathodic protection cable commonly used in North America to connect High Silicon Cast Iron Anodes to Direct Current power sources. The reader is cautioned that this presentation is not exhaustive or comprehensive, and that it is intended as an introduction to the subject. Note: dimensions listed are nominal, and have been abbreviated for convenience

Copper Conductors CP cable always consists of copper conductor insulated from the surrounding soil or electrolyte. In North America, Anode Lead Cables usually contain one of the following conductor options:

TABLE 1: NORTH AMERICAN COPPER CONDUCTORS for CP Cables

Size		Nominal OD		Nominal Area		Resistance 25C		Nominal Strength	
AWG	Stranding	inch	mm	sqin	sqmm	ohms/kft	ohms/km	lb	kg
8	7 - 0.0486	0.15	3.8	0.013	8.37	0.41	1.35	480	220
6	7 - 0.0612	0.19	4.8	0.206	13.3	0.26	0.85	760	345
4	7 - 0.0772	0.23	5.8	0.033	21.2	0.16	0.53	1200	545
2	7 - 0.0974	0.30	7.6	0.052	33.6	0.13	0.42	1900	860

Note: Manufacturers may compress conductors, resulting in a smaller than tabulated Nominal OD.

TABLE 2: STANDARDS AND OPTIONS FOR AMERICAN CATHODIC PROTECTION CABLE CONDUCTOR (Details have been omitted for simplicity)

CONDUCTOR Standard:	**COPPER WIRES** ASTM B-3 Soft or Annealed		**STRANDS**, ASTM B-8 Concentric Lay		
Typical Specification:	Copper conductors shall be Class B stranded, compressed, annealed, uncoated copper in accordance with ASTM B-8 latest edition.				
Cautions:	Some specifications for conductors may require "flexible" cable with many small strands (i.e. Class C = 19), or with "tinned" wires				
Characteristics:	CLASS C 19 STRANDS (for flexibility)	CLASS B 7 STRANDS (most common)	Common Wire Sizes Note 1.	Area	
				sqmm	sqin
			8	8.3	0.013
			6	13.3	0.0206
			4	21.1	0.033
			2	33.7	0.052

NOTE 1: Wire Size: Wire diameters conform to various gauging systems. Typical North American CP cable bulletins refer to cable sizes by "Gauge" without defining the gauging system used, and "Stranding" which references the number of (wire) strands and the inch decimal diameter of the wires. Some refer to the acronym "AWG" which has become widely used to mean "wire size" in the CP trade, but technically, the wire may be manufactured to a different gage system. This difference has virtually no practical significance to CP performance. It is also usual for manufacturers to reference Standards ASTM B-3 (wire) and B-8 (strands). In fact ASTM B-3 references ASTM B258 Specification for …AWG Sizes … of wires….

Table 3 on page 2 compares nominal conductor sizes for Metric American and British Gauges.

TABLE 3

WIRE GAUGE COMPARISON

METRIC - AMERICAN - BRITISH

CABLE DIMENSIONS			APPROXIMATE EQUIVALENT		
RESISTANCE OHMS/KM	AREA mm2	DIAMETER mm	METRIC GAUGE mm2	AMERICAN WIRE GAUGE	BRITISH STANDARD GAUGE
8.3	2.1	1.6		14	16
6.9	2.5	1.8	2.5		15
5.2	3.3	2.1		12	14
4.3	4.0	2.3	4		13
3.3	5.3	2.6		10	12
2.9	6.0	2.8	6		11
2.1	8.3	3.3		8	10
1.7	10.0	3.6	10		9
1.3	13.3	4.1		6	8
1.1	16.0	4.5	16		7
.83	21.1	5.2		4	5
.70	25.0	5.6	25		4
.52	33.7	6.5		2	3
.50	35.0	6.7	35		2
.41	42.3	7.3		1	1
.35	50.0	8.0	50		
.33	53.5	8.3		1/0	1/0
.26	67.5	9.3		2/0	2/0
.25	70.0	9.4	70		3/0
.20	85.2	10.4		3/0	4/0
.18	95.0	11.0	95		5/0
.16	107.2	11.7		4/0	5/0
.14	120.0	12.4	120		7/0

CABLE INSULATIONS

In North America, CP cable usually has one of the following insulation / jacket options:

- **A single layer of Polyethylene insulation 0.11" (2.8mm) thick** used in the majority of surface groundbeds, and commonly called "HMWPE" (High Molecular Weight Polyethylene)
- **A fluorocarbon polymer insulation 0.02" (0.5mm) protected by a polyethylene jacket .06" (1.5mm) thick**, primarily for deep well groundbeds where halogen gases, particularly chlorine, are evolved and concentrated around the anode and cable. These types are commonly called "KYNAR" or "HALAR".

CAUTION: Although it may be convenient to use acronyms or trade names such as "HMWPE", "KYNAR" and "HALAR", these terms do not accurately define the technical differentiations found in specifications and contracts. For this reason CP practitioners should be familiar with the Standards and options for Copper Conductors and Insulations, and be aware of the sub classes and "boiler plate" within Standards.
Tables 5 (page 5) and 6 (page 6) provide examples of technical differentiation between insulation types.

HMWPE = HIGH MOLECULAR WEIGHT POLYETHYLENE

Polyethylene (PE) is polymerized ethylene $(C_2H_4)_n$, a highly crystalline, lightweight thermoplastic.

Outstanding characteristics are chemical resistance, toughness (even at low temperatures), dielectric properties, water vapour impermeability, and relatively high softening temperature.

The term Polyethylene usually refers to polymerized ethylene of molecular weight > 6000, commonly referred to as High Molecular Weight Polyethylene (HMWPE).

Copolymers of polyethylene are also widely used and are sometimes referred to as polyethylene even though PE may comprise only 50% of the total material.

PE may be "linear" or "branched", as determined largely by the pressure and temperature in the manufacturing reactor. Linear PE involves relatively low pressure / temperature compared to Branched PE. For Linear PE, density is also affected by the quantity of comonomer used with the ethylene feed stock. The proportionally more the comonomer, the lower the density.

A range of density grades of High Molecular Weight Polyethylene are available. ASTM D 1248, for example, recognizes 4 distinct Types of PE according to density, whereas the Condensed Chemical Dictionary defines 3 Grades for HMWPE as *Low*, *Medium* or *High*.

It should be noted that ASTM D1248 does not use the term *High Molecular Weight* anywhere in the Standard. Even though most manufacturers of PE insulated cable for the Cathodic Protection industry reference ASTM D 1248, they also include the words *High Molecular Weight Polyethylene (HMWPE)* in their product description. Kalas Manufacturing, for example, describes their Cathodic Protection Cable Standard insulation as *Low Density High Molecular Weight Polyethylene (HMWPE), 75°C, 600 Volt; conforms to the following*

specifications or testing methods: ASTM D 1248, Type 1, Class C, Category 5, Grade E-4 and E-5. Table 4 lists the Density ranges as defined by the specification and compares these values to plastics industry terminology. Table 5 lists Molecular Weight according to industry terminology

TABLE 4: Density of PE and Plastics Industry Terminology

D1248 *TYPE*	Density Range	Plastics Industry		
		Terminology	Density	Acronym
I	0.910 to 0.925	Low Density	<0.92	LDPE
II	0.926 to 0.940	Medium Density		HDPE
III	0.941-0.959	High Density	>0.94	HDPE
IV	0.960 and higher			UHDPE

TABLE 5: Molecular Weight of PE, and Plastics Industry Terminology

MOLECULAR WEIGHT	TERMINOLOGY	ACRONYM
50,000 to 250,000	Low Molecular Weight	
250,000 to 1,500,000	High Molecular Weight	HMWPE

XLPE = CROSSLINKED PE (Irradiated PE)

A radiation process is used to change the physical properties of materials through ionization of atoms and molecules to create free radicals. Crosslinking of wire and cable insulation can improve stress-crack, abrasion and deformation resistance, service temperatures, and resistance to the action of fluids.

Polyethylene insulation or jacketing for CP cable is not necessarily "cross linked" (XL) or "irradiated." "EXAR" (Champlain) and "CATHORAD" (Judd) are irradiated kynar insulations, with a HMWPE jacket. XLPE - PVC (insulation / jacket) cable is a commonly specified in the UK, wherein the XL prefix means "irradiated".

PVC = POLYVINYL CHLORIDE

The most significant commercial vinyl, made from chlorine and ethylene, with a polymerization reaction, ending up partially crystalline. PVC is sensitive to environmental salt content.

History of PVC and HMWPE for CP Cable Insulation:

Reference: Hugo, L.A. et al., "Advantages of HD Polyolefin for CP" Material Protection, Feb. 1962, pp 38 - 44. Before HMWPE became the dominant insulation for CP cable in North America, other materials experienced problems. Rubber insulated, neoprene jacketed cable failed in ground saturated with oil or gas, or when the neoprene jacket was damaged. 600V PVC cable failed at locations in or near salt water due to insulation blistering and embrittlement. Failures were reduced from salt by insulating with PE and jacketing with PVC, but in due course, failures attributed to distortion of the PVC occurred. Phillips Petroleum carried out extensive testing and development which led, in part to the wide acceptance of HMWPE insulation of 0.110" (2.8mm) thickness in North America. Eventually, due to problems in deep wells attributed to concentration of chlorine, most deep well applications in North America utilize Kynar or Halar insulated, HMWPE jacketed cables, rather than standard HMWPE.

HMWPE in chlorine (halogen) environments:

Reference: Thomas F. Lewicki, "Premature Failure of Anodes in Deep Ground Beds", Corrosion/80 Paper 243 (NACE).

When HMWPE was used in deep wells where halogen gases evolved under concentrating conditions, failures were experienced in anode beds. Investigations made by Thomas Lewicki for The US Air Force in the 1970's established that the HMWPE, rather than the anode or connection seal, was the problem; and that HALAR insulation was reliable. KYNAR cables have also proven reliable in deep well applications.

HALAR and KYNAR insulation:

HALAR and KYNAR are trademark-registered plastics. CP cables made with HALAR and KYNAR and jacketed with HMWPE, are more costly than plain HMWPE.

HALAR is a flouropolymer (Ethylene-chlorotrifluoroethylene copolymer, ECTFE) sold by Ausimont. ECTFE is resistant to most corrosive chemicals and organic solvents at room and elevated temperatures. Its dielectric constant (2.6) is low and stable over a wide temperature range.

KYNAR is Polyvinylidene Fluoride (PVDF), which can be crosslinked by irradiation. It is a product of Atochem very resistant to attack or penetration by most corrosive chemicals and solvents, including inorganic acids, oxidants, alkalines, halogens and hydrocarbons.

HALAR and KYNAR becomes "notch sensitive" with increasing thickness; but the 0.20" (0.5mm) thick insulation for CP cables is thin enough to functions reliably under 0.07" thick HMWPE jacketing.

Caution: The CP practitioner must be aware that HALAR or KYNAR as trade names in contract documents do not precisely define the quality of material which the customer's application may require. One manufacturer's KYNAR insulated cable may not be to the same standard or grade as another manufacturer's KYNAR cable.

SLEEVES: Added protection against halogen attack may be obtained by the installation of a heat shrink sleeve around the insulation in the vicinity of the anode. One customer requires 2m of radiation crosslinked adhesive coated heat shrinkable polyolefin sleeve of 2mm wall thickness minimum (epoxy) encapsulated for 130mm in the anode.

INSPECTION, TESTING AND HANDLING OF CP CABLES For a cable to serve reliably it must arrive at the site and be installed without damage to its insulation. Avoid:

- Contact with sharp, penetrating, or highly abrasive surfaces (cable protectors for anode or epoxy)
- Bending or forming to tight radii (temperature sensitivity, packaging design)
- Contact with potentially damaging chemicals or radiation (excessive sunlight).

Cable can be tested for defects in the insulation:

- **At the Anode-Cable Assembly Plant:** Holiday Detector: Tinker & Razor Model APW, Pulse Type, at (say) 18000V output to meet ARAMCO 17-SAMSS-007 requirements.
- **At the Cable Manufacturer's Production Plant**: Voltage Testing: ICEA S-61-402, NEMA WC5: Voltage and Spark Tests to verify insulation integrity.

Other methods and equipment may be applicable, but the inspection tests described have been practically applied commercially in North America. For the UK, BS 6195 (Appendices C and D) describes Production and Manufacturer wet and spark testing for cables specified and used by CP practitioners of British persuasion.

TABLE 6

TYPICAL WORDING from VARIOUS NORTH AMERICAN STANDARDS, with options FOR CATHODIC PROTECTION CABLE INSULATION

(Details have been omitted for simplicity)

INSULATION	Details and Comments		
Typical "HMWPE"	Insulation shall conform to ASTM D1248 Type 1, Class C, Category 5, Grades E-4 and E-5. Surface Printed "Manufacturer Name, AWG Size"		
Cautions:	Although "HMWPE" may appear to infer "High Density", this is a misinterpretation. HMWPE may be of Low, Medium or High Density. Refer to manufacturers' Specifications.		
Material: Thickness (usual) 0.110" (2.8mm)	POLYETHYLENE Molding and Extrusion	CLASS Additives and Antioxidants	GRADE: (for example: E4 or E5) "E" for insulation, "J" for jacketing "Grade" related test qualities include:
Standard:	ASTM D-1248	A (None)	Tensile Elongation Crack Resistance Dielectric constant Resistivity Water Stability
		B (Some)	
		C (Weather Resistant)	
Typical "KYNAR" Spec. for PVDF = Polyvinylidene Fluoride	Primary Insulation shall be irradiated cross-linked extruded PVDF. The Outer Jacket shall be black, high density and high molecular weight polyethylene (HMWPE) conforming to ASTM D1248, Type 3, class C Category 5 of minimum density 0.941 grams per cubic centimetre.		
Comment and Caution:	Kynar **is not always** irradiation cross-linked for improved resistance to flow at temperatures above normal melt point or for improved resistance to electron or gamma radiation. Grade/Density influences the efficiency of cross-linking. Manufacturers use Trade Names such as "PERMARAD" (Raychem) and "CATHORAD" (Judd), and their bulletins may not specify Grade/Density. Kynar is more costly than HMWPE.		
Typical "HALAR" Spec. for ECTFE = Ethylene Chlorotri-fluoroethylene	Primary Insulation shall be natural Halar 0.020" minimum thickness. The Outer Jacket shall be black High Molecular Weight Polyethylene of minimum wall thickness 0.064", conforming to ASTM D1248 Type 1, Class A, Category 5, Grades E4 and E5, Tensile Strengths J1 and J3.		
Comment and Caution:	Halar is more costly than HMWPE. For selection, specifications and properties should be assessed. A minor point: In this instance the specification needed only to reference the Grades J4 and J5 for the HMWPE jacket over the Halar insulation.		

References:

1. Modern Plastics Encyclopedia 1990
2. The Condensed Chemical Dictionary Fourth Printing (1969)
3. ASTM D 1248 Polyethylene Plastics Molding and Extrusion Materials.
4. ASTM D 1351 Polyethylene Insulation for Electrical Wire and Cable

5.Lewicki T.F., "Premature Failure of Anodes in Deep Ground Beds", Corrosion/80 Paper 243 (NACE). [L24]