

CABLES AND CABLE GLANDS FOR HAZARDOUS LOCATIONS

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Abstract – This paper explores the various standards and requirements for the certification, selection, use, and installation of cables and cable glands used in explosive gas atmospheres throughout the world. International and North American requirements for cables and cable glands will be examined and compared. In North America, the National Electrical Code (NEC) and Canadian Electrical Code, Part I (CEC) define the requirements for the types of cable that are permitted to be used in different hazardous (classified) locations. In North America, standards exist for certifying cables for use in hazardous locations. These standards have now evolved to allow for additional cable types beyond metal clad (MC) and TECK 90 cables that are primarily used. In Canada, a new edition (2018) of the Hazardous Location Cable and Cable Gland standard has been published, and this should help to clarify the intended range of cable types that could potentially be approved for hazardous locations in Canada. In the United States (US), the NEC defines the types of cables that can be used in hazardous locations, and UL 2225 provides the means to approve Hazardous Location (HL) cables for the US. The International Electro-Technical Commission (IEC) on the other hand does not require cables to be specifically approved for explosive gas or dust atmospheres and instead only provides guidance within IEC 60079-14 on the selection of cables. In all jurisdictions, cable glands for use in explosive gas atmospheres are required to be approved for the location they are being installed in or with a method of protection suitable for the location that they are being installed in, but there are differences in the various standards and requirements.

Index Terms — hazardous locations, explosive atmospheres, cables, cable glands, hazloc, installation

I. INTRODUCTION

Cable glands (cable entry devices) used in hazardous locations are intended to provide the safe connection of suitable cables to enclosures, maintaining the explosion protection and ingress properties of equipment. In North America, the NEC and the CEC prescribe the requirements for both cable glands and cables. Both codes require the use of cables and glands that are certified to specific standards depending on the explosive environment they are being used in. Standards used in both Canada and the US are similar in many respects, but

there are some significant differences in the cables that can be used.

In jurisdictions following IEC requirements, there are product standards for hazardous location cable glands. However, unlike NEC and CEC jurisdictions, there are no specific product standards for hazardous location cables. Requirements for cables are in IEC 60079-14: Electrical installations design, selection, and erection. IEC 60079-14 is an installation standard, not a product standard and cables are not certified to this standard. This standard provides guidance for the minimum requirements for cable but does not define specific tests or construction specifically for hazardous location cable. Instead, wiring for ordinary locations meeting certain minimum requirements is permitted to be used. Other than in IEC 60079-14, the IEC 60079 series of standards do not address cables. They do however address the cable glands that are used with cables, and there are requirements in the IEC 60079 series that have construction and test requirements for the certification of cable glands.

In addition to the cables permitted by the NEC, CEC, and IEC, cable usage has also been addressed in other standards and recommended practice documents for installations offshore or on ships. For example API RP14 and RP14FZ provide guidance for wiring in classified locations on fixed and floating offshore petroleum facilities. While there appear to be a wide variety of different allowances for cables in various areas, all are considered safe by the authorities having jurisdiction in those areas.

Different jurisdictions use different terminologies for areas that may contain explosive gas atmospheres. Throughout this paper, the terms hazardous locations, classified locations and areas containing explosive gas atmospheres are used interchangeably.

II. EXPLOSIVE GAS ENVIRONMENTS

While definitions and terminology vary slightly between the IEC, CEC, and NEC, explosive gas atmospheres, hazardous locations, or classified locations are those areas that have a likelihood of having an atmosphere that contains a flammable gas (or gasses) in a concentration that is capable of igniting and causing an explosion/deflagration.

In jurisdictions following IEC requirements, all installations are classified per the Zone system of area classification. This system divides hazardous areas for explosive gases into three zones based on the likelihood and probable duration of the explosive gas being present. All electrical equipment used in these classified areas needs to be protected using one or more methods of protection permitted for the area's classification. For cables, there is no difference in the requirements for Zone 1 and Zone 2.

All new installations in Canada since the 1998 CEC are classified per the Zone system of classification. Existing facilities are permitted to continue to use the Division classification system, or they can reclassify to the Zone system. Regardless of the type of area classification, the equipment used in Canada is often a mix of equipment types with some being certified to legacy CSA standards and others being approved to the CAN/CSA C22.2 No. 60079 series standards. These standards are adoptions of the IEC 60079 series standards with Canadian specific deviations included. Equipment used in Zone locations is often equipment that has been approved and marked with class and division markings. Equipment used in locations that are Division classified could also be equipment that is marked with Ex methods of protection. It should be noted that in Class I Division 1 locations, only equipment approved for Class I Division 1 or intrinsically safe equipment can be used. A new table, Table 18, has been added to CSA C22.1-18 (CEC Part 1), that lists the methods of protection and the equipment permitted in hazardous locations in Canada.

In the US, installations may also be classified per the Division system or the Zone system. Unlike Canada though there is no requirement to classify areas in new installations per the Zone system. As there are no rules explicitly requiring the use of Zone classification, the adoption of the Zone system has been slower in the US than in Canada, and approximately 95% of installations continue to use the Division Classification [1]. As with Canada, the NEC allows a mix of equipment. However, unlike Canada, when using equipment certified as Class I and not marked with a method of protection (i.e. not marked AEx...) it would need to be additionally marked as Class I Zone 1 or Zone 2 as applicable, and a gas group equivalent to the gas groups it is listed for. For example, a piece of equipment approved and marked as Class I Groups C, D can be used in an area classified as Zone 1 IIB. The equipment needs to be and per the rules of NEC Article 505 [2], is permitted to be marked Class I Zone 1 IIB, without an AEx or method of protection marking, in addition to its Class I Group C, D marking. In Canada, the marking of "Zone" is not recognized in the CEC installation standard so the marking would have no meaning with respect to the installation Code in Canada.

In the US and Canada, there are different requirements for cable usage depending on the classification of the area that the cable will be used in

III. HAZARDOUS LOCATION CABLES

A. Wiring Methods

1) *NEC*: Requirements for wiring methods are in the NEC. Class I Division 1 and 2 wiring methods are located in NEC Article 501 and Class I Zone 0, 1, and 2 wiring methods are in Article 505. Article 504 provides additional requirements for intrinsically safe wiring methods permitted in all locations. Conduit is still largely used for installations in Class I Division 1 locations in the US, however cables are permitted for use under restricted and special conditions.

Table 1 outlines the permitted wiring methods in Class I Division 1 areas. Per NEC Article 501, MC-HL and ITC-HL are permitted to be used in Class I Division 1 areas provided they are used only in industrial establishments with restricted public access, where the conditions of maintenance and supervision ensure that only qualified persons service the installation. These cables must have a gas/vapor tight continuous corrugated metallic sheath with an overall jacket of suitable polymeric material. MC-HL cables must have a separate equipment grounding conductor(s) per 250.122. ITC-HL must be installed per the requirements of Article 727. The cables must be terminated with fittings listed for the application.

Where flexible connections are needed such as at motor terminals, TC-ER-HL is permitted to be used with the same restriction of being used in industrial establishments with restricted public access and accessible for service only by those qualified. Additionally, use is limited to 600 volts or less, and the cable must be protected from damage by location or a suitable guard.

TABLE 1
NEC CLASS I DIVISION 1 WIRING METHODS

General	Threaded rigid metal conduit or threaded steel intermediate metal conduit
	MI cable with fittings listed for the location and supported to prevent tensile stress at the terminals
	MC-HL per requirements of NEC 501.10(A)(1)(c)
	ITC-HL per requirements of NEC 501.10(A)(1)(d)
Flexible	Optical fiber cables
	Flexible cord per 501.140 with cord connectors listed for the location
	Flexible fittings listed for the location
	TC-ER-HL per requirements of 501.10(A)(2)(3)

The fourth edition of standard UL 2225 was published in 2013 (including revisions through Jan 29, 2016) [3]. It provides the construction and testing requirements for cables and cable glands that are permitted for installation per the National Electrical Code. UL 2225 provides construction and test requirements for the approval of MC-HL, ITC-HL, and TC-ER-HL. The requirements in UL 2225 are in addition to the ordinary location requirements for the cables. Additional testing requirements include a test for low-temperature impact, an impact test for mechanical damage, a crush test, and a flame test.

In Class I Zone 1 locations, all cables permitted in Class I Division 1 are also allowed. Additionally, type TC-ER-HL cable is permitted for use where it is not subject to physical damage for applications limited to 600V or less and for cable diameters of 1 inch or less. TC-ER-HL needs to be installed per the provisions of Article 336 including the restrictions of Article 336.10(7)

In Class I Division 2 and Zone 2, in addition to HL rated cable the NEC also permits the use of a number of non-HL cables. In addition to the aforementioned HL cables, ordinary location MC, MV, TC, TC-ER, ITC, ITC-ER, PLTC, and PLTC-ER are permitted to be used when installed in accordance with the requirements outlined in NEC Article 501.10(B) for Class I Division 2 and Article 505.15(C) for Class I Zone 2.

2) *CEC*: The CEC outlines the types of cables that can be used in the different classified locations in Canada. Wiring in Zone 0 locations is always required to be intrinsically safe. The only exception is that there is an allowance permitting non-intrinsically safe cable marked -HL to pass through the Zone 0 when it is protected from mechanical damage and where it passes completely through without any connections or fittings within 300mm of the Zone 0 boundary.[4]

TABLE 2
CEC WIRING METHODS ZONE 1 AND CLASS I DIVISION 1

General	Threaded rigid metal conduit
	Hazardous location cable (HL)
	Intrinsically safe wiring
Flexible	Extra-hard usage flexible cord with a bonding conductor for portable lamps or other portable utilization equipment
	Extra-hard usage flexible cord with a bonding conductor where fixed methods cannot provide the required degree of movement and where the cord is protected from damage by location or a suitable guard
	Explosion-proof or Ex d glands if entering an enclosure required to be explosion-proof or Ex d; terminated with a suitable Ex e gland when entering an Ex e enclosure

Zone 1 and Class I Division 1 locations do not always allow for the use of the same equipment, but the same cable types (Table 2) are permitted. Cables used, except for intrinsically safe systems, need to be hazardous locations (HL) cables. The exception to this requirement is that extra-hard usage cable can be used for portable lamps or utilization equipment or where fixed wiring cannot provide the flexibility needed for fixed or portable utilization equipment. When used for fixed equipment where the degree of flexibility requires it, the cord must also be protected from damage by location or by guarding [5].

The most commonly used HL cable in Canadian installations is TECK-HL. TECK-HL is cable approved to C22.2 No. 131 (Type TECK 90 cable) [6] and further tested and certified to CSA C22.2 No. 174 [7]. TECK 90

cable consists of single or multi-conductors with an inner jacket and an interlocking metal armor. Unlike MC-HL cable, the TECK-HL armor is not a continuously welded armor. Full construction details for TECK 90 cable can be found in CSA C22.2 No. 131.

The choice of wiring methods in Zone 2 and Class I Division 2 locations is greatly expanded versus Class I Division 1 or Zone 1 allowing a number of non-HL cable types to be used. In addition to the cable types permitted in Zone 1 or Class I Division 1 locations, cables permitted in Zone 2 and Class I Division 2 are:

- Type TC Cable installed in cable tray per rule 12-2202
- Armored cable with an overall non-metallic jacket such as TECK90, ACWU90, RC90, RA90
- Type CIC cable installed in cable tray per rule 12-2202 where
 - the voltage rating of the cable is not less than 300V
 - circuit voltage is 150V or less
 - circuit current is 5A or less

In Canada, the standard CSA C22.2 No. 174 provides the construction and testing requirements for hazardous location cables and cable glands. Up until the most recent edition of CSA C22.2 No. 174 the cable type or construction requirement was not defined. It was strictly a performance-based standard, i.e. if the cable passed the required tests, it could be approved as "HL" cable. However, earlier attempts to approve cable types other than TECK cable were not accepted by some regulators, certifiers, and users and the market defaulted to the use of TECK-HL.

In January 2018 a new edition of CSA C22.2 No. 174 was published. Previous editions of this standard had a statement indicating that there were no construction requirements for the standard. This technically meant that any certified cable capable of passing the additional tests of the CSA C22.2 No. 174 should be able to be marked as -HL and therefore used in hazardous areas. In practice though, early attempts to certify and get acceptance for non-TECK HL cables were rejected leading TECK-HL cable to being the dominant cable used in the Canadian market.

The new edition lists all of the cable types (Table 3) that can be additionally tested and marked -HL per CSA C22.2 No. 174. The hope is that it will now be more evident to certification bodies, regulators, users and manufacturers that cables other than TECK 90 can be certified for hazardous locations.

TABLE 3
CABLE CONSTRUCTIONS PERMITTED TO BE
ADDITIONALLY APPROVED TO CSA C22.2 NO. 174

CSA Standard	Cable Type	Restrictions
C22.2 No. 51	Armoured cables	
C22.2 No. 96	Portable power cables	
C22.2 No. 96.1	Mine power feeder cables	
C22.2 No. 123	Metal sheathed cables	
C22.2 No. 124	Mineral-insulated cable	
C22.2 No. 131	Type TECK 90 cable	
C22.2 No. 230	Tray cables	
C22.2 No. 239	Control and instrumentation cables	Type ACIC only
C22.2 No. 245	Marine shipboard cable	
C68.10-14	Shielded power cable for commercial and industrial applications, 5-46 kV	

3) *IEC*: The requirements for cables used in explosive environments are found in IEC 60079-14 (Explosive Atmospheres Part 14: Electrical Installations Design, Selection, and Erection) [8]. There is no specific approval or specific type of cable that is required. However, there are minimum requirements that cables must meet. These requirements are the same whether the cable is being used in a Zone 1 or Zone 2 area. Cable requirements for cables used in fixed installations and for flexible cable (excluding intrinsically safe circuits) are in Section 9 of IEC 60079-14. Cables used in intrinsically safe systems have requirements outlined in section 16. See also IEC 60079-11 for additional information on Ex i equipment requirements [9]

Cables are not permitted to be of the “easy tear” type (i.e. with low tensile strength sheaths) unless installed in conduit. For fixed installations, cables need to be:

- Sheathed with thermoplastic, thermosetting or elastomeric materials and circular and compact. Any fillers need to be non-hygroscopic and any bedding or sheath must be extruded,
- Mineral insulated metal sheathed, or
- Of a special type that is compact, with any bedding or sheath extruded and with any fillers of a non-hygroscopic type

Additionally, where gas or vapor migration is likely to occur through the interstices between the individual cores of the cable, and the cable goes from a hazardous location to a non-hazardous location or goes between different Zones, then the construction must be taken into account and appropriate control measures considered to prevent gas migration.

Flexible cables that are used in fixed installations (excluding intrinsically safe circuits) shall be: (a) ordinary tough rubber sheathed, (b) ordinary polychloroprene sheathed, (c) heavy rubber sheathed, (d) heavy polychloroprene sheathed, or (e) plastic insulated and of equal robust construction to heavy rubber sheathed flexible cables. Flexible cables for portable and moveable equipment (excluding intrinsically safe circuits) shall have a heavy polychloroprene or other equivalent synthetic elastomeric sheath, heavy tough rubber sheath or an equally robust construction.

4) *Other*: There are a number of standards and recommend practices (RPs) published that allow for or recommend the use of cable outside of what is allowed in the NEC or CEC. As the IEC does not have a specific standard for hazardous location cables, the RPs are generally within the scope of what is permitted per IEC 60079-14. Any national or local installation requirements should always be known before specifying or using a cable, as there could be potential deviations to what is permitted per the IEC, NEC or CEC.

A number of RPs are for offshore or shipboard use and allow for the use of marine shipboard cable in addition to the cables permitted in the NEC, CEC or IEC. For example, the Canadian Transport Canada standard TP127 (Ships Electrical Standards) [10] allows the use of braided armored marine cable in Zone 1 locations. API 14F (Design, Installation, and Maintenance of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class 1, Division 1 and Division 2 Locations) [11] in addition to those cable types in the NEC, allows the use of armored and sheathed marine shipboard cable in Class I Division 1 classified locations.

B. Certification

In both Canada and the US, cables for use in Class I Division 1 or Zone 1 require specific approval and marking for hazardous locations. Cables need to meet the requirements for the ordinary location cable standards and meet the more rigorous testing of the applicable CSA or UL hazardous location standard. While there are some common tests for cables in CSA C22.2 No. 174-18 and UL 2225, there are also some significant differences.

Both the CSA and UL standards have additional test requirements for low-temperature impact, crushing, and flame testing. These tests provide an additional safety factor for cables that already meet the ordinary location standards, but are intended to be used in hazardous locations. The intention is to add a safety factor to possible situations where damage may occur to the cable that could potentially cause ignition of an explosive gas atmosphere.

In addition to these tests, the CSA standard has additional testing for armored cable tension and flexibility (interlocked armor cable), cable jacket tear strength (unarmored cable) and a pull through metal plate test (unarmored cables). Unlike the requirements in the US, Canadian armored cable is not required to be continuously welded. As a continuous weld is not needed, the CSA standard includes a test that evaluates

the ability of the cable to remain intact under tension and when flexed. The cable jacket tear strength and pull through metal plate tests for unarmored cables are new tests added to the recent version CSA C22.2 No. 174 standard to address some concerns on the performance of cables not having armor. The intention of having the cable jacket tear strength is to prevent the use of "easy tear" cables, and it quantifies the requirement found in IEC 60079-14 that prohibits the use of "easy tear" cables. The pull-through metal plate test is intended to simulate possible issues during installation of cable that may cause damage to the cable. The test is the same as the test used in CSA C22.2 No. 245 for marine shipboard cable and extends the requirement to all non-armored cable types that are intended to be used in hazardous locations.

IV. CABLE GLANDS

In North America, as with cables, cable glands are approved to specific national standards. In other locations, subject to the requirements of the IEC, cable glands, unlike cables, must be specifically approved for hazardous locations per the IEC 60079 series of standards.

Cable glands used need to be of the correct type for the cable being used and need to meet the requirements for the area they are being used in and the equipment they are connecting to. Cable glands will provide a degree of environmental and ingress protection and provide protection required for the equipment they are being connected to and the hazardous location they are being installed in. They are intended to maintain the required ingress and explosion protection integrity of the enclosures that they are being used in conjunction with.

A. NEC

Requirements for cable glands for use in hazardous locations are located in the same standard as hazardous location cables - UL 2225 [12]. UL 2225 includes construction and testing requirements for cable glands being marked with Class I approvals (e.g. Class I Group B, C, D) and also for cable glands being marked AEx (e.g. Class I Zone 1 AEx e IIC). As the permissible cable types for hazardous areas are TC-ER-HL and MC-HL, cable glands approved to UL 2225 are designed to work with these cables. Additionally, since flexible cord is permitted, subject to certain restrictions, cable glands are also evaluated for use with this type of cable.

UL 2225 tests glands with the specific cables they are designed and approved for, therefore, the glands usage is limited to those cable types that they have been evaluated with. Part II of UL 2225 addresses approval of cable glands for Class I Division 1. This section provides the construction and testing requirements for explosion-proof and dust-ignition-proof cable sealing fittings. Tests included in this section are:

- Torque
- Resistance to impact tests
- Explosion tests
- Hydrostatic pressure tests

- Dust penetration tests
- Leakage tests
- High humidity tests
- Non-metallic material tests

Part III of UL 2225 provides the construction and testing requirements for AEx cable fittings and extra-hard usage cord connectors.

Tests included in this section are:

- Unarmored cable fitting strain relief performance
- Strain relief test
- Mechanical strength
- Armored cable fitting strain relief performance
- Flameproof fitting or connector performance
- Increased safety fitting or connector performance
- Dust exclusion by enclosure "t" or "tD"

The flameproof fitting or connector performance in Part III refers back to testing in Part II for resistance to impact, explosion, and hydrostatic pressure. Therefore it is required that the Class I Zone 1 AEx d cable glands meet the same test requirements as Class I Division 1 cable glands.

In Class I Division 1 locations, cable glands must be listed for the application, and cable seals need to be installed at all terminations. Cable glands used in Class I Division 1 are therefore required to be certified to the requirements UL 2225. Class I Division 2 cable glands must also be listed. However, as not all equipment is required to be explosion-proof and cables permitted in Class I Division 2 include cables outside the scope of UL 2225, cable glands do not necessarily need to be evaluated to that standard. In Class I Division 2 locations cables entering enclosures required to be explosion-proof or flameproof need to be sealed at the point of entry to the enclosure. These cable glands would be required to meet the requirements of UL 2225.

Cable seals are required for cables at the first point of termination in Class I Zone 0 locations. These seals are not required to be explosion-proof or flameproof. Their purpose is only to minimize the potential of gas migration through the cable. In Class I Zone 1 locations, cables entering explosion-proof or flameproof enclosures need to use cable glands per UL 2225 Class I or Class I AEx d sealing type glands. Cables are also required to be sealed at the point where they leave the Class I Zone 1 area, except where the cable is sealed at the termination point. In Class I Zone 2 sealing type cable glands are also needed for cables entering enclosures that are required to be explosion-proof. [13]

B. CEC

The CEC has a general requirement, Rule 2-024, that requires, with few exceptions, that electrical equipment is approved. In general, this means that equipment is certified by an accredited agency to the applicable product standards, although there are means to have equipment

approved by the regulatory authority. For this reason, requirements to use approved equipment and cables is not explicitly mentioned throughout the Code as all equipment must meet the requirements of Rule 2-024 and therefore must be approved. Cable glands being used must be approved to the requirements outlined in Section 18 (Hazardous locations) or Annex J18 (Hazardous locations classified using the Division system) as well as other general sections of the Code.

The tests in CSA C22.2 No. 174 for cable glands are similar to those in UL 2225. Tests include:

- A twist test for cable glands intended for use with flexible cords and portable cables
- Flammability
- Explosion propagation (Class I glands with integral seals)
- Hydrostatic pressure test (Class I glands with integral seals)

Cable glands must also comply with the requirements of CSA C22.2 No. 18.3, CSA C22.2 No. 25 and CSA C22.2 No. 30 as applicable.

CSA C22.2 No.174 also provides requirements for a compression cable gland, whereas in UL 2225 there is no compression cable gland. Compression seals must meet the requirements of CSA C22.2 No. 30. While the standard does allow for the approval of this type of sealing gland, it is unlikely that any end user or inspector would currently accept it in a field installation. As they are required to go through the same performance testing requirements as the traditional cable seals (sealed with a compound), they should, in theory, be acceptable for Class I use.

1) *Class I Division 1*: Per the requirements of the CEC products used in Class I Division 1 areas must be approved for Class I Division 1 or would need to be for an intrinsically safe wiring system. This means that except for IS systems, cable glands in Class I Division 1 must be certified to CSA C22.2 No. 174.

2) *Zone 1*: For Zone 1 locations, in addition to cable glands allowed in Class I Division 1, there are a number of different Ex protection methods permitted. Of these the most commonly used Ex protection methods are Ex e and Ex d. Cable glands used in Zone 1 locations will be Class I Division 1, Ex d, or Ex e rated.

Class I Division 1 rated cable glands are those approved to the requirements of CSA C22.2 No. 174. Ex d cable glands are certified to the requirements of CAN/CSA C22.2 No.60079-0 and CAN/CSA C22.2 No. 60079-1, and Ex e cable glands are certified to the requirements of CAN/CSA C22.2 No.60079-0. The Canadian standards CAN/CSA C22.2 No. 60079-0 and No. 60079-1 are adoptions of IEC 60079-0 and IEC 60079-1 with deviations.

CAN/CSA 60079-0:15 (Canadian adoption of IEC 60079-0 Ed 6.0) takes a deviation to the requirements and disallows clamping by filling compound. A note is added to state that clamping by filling compound is not an acceptable method in Canada and Clause A.3.1.2 "Cable glands with clamping by filling compound" is deleted. [14]

CAN/CSA 60079-1:16 only has a deviation on threaded joints changing the wording in Clause C.2.2.1 from "flush" to "+1/2" in reference to NPT thread gauging bringing it in line with standard Canadian requirements. [15]

3) *Zone 2 and Class I Division 2*: Class I Division 2 and Zone 2 classified locations allow the same equipment to be used in each and therefore the same cable gland requirements exist. The rules of the Code require cable glands to maintain the ingress properties and explosion protection properties of the enclosure they are going into. There are no Class I Division 2 rated cable glands. Glands used in Class I Division 2 locations will either be a Class I Division 1 gland, Ex d gland, Ex e gland or it will be an ordinary location gland with a Type rating.

As ordinary location (non-classified) equipment is permitted to be used, cable glands being used with this equipment is required only to meet the ingress or environmental protection rating of the enclosure. For example, if a Type 4 enclosure rating is required and a Type 4 enclosure is being used, then the cable gland must be certified as Type 4 to maintain the environmental rating. Where an enclosure is required to be explosion-proof or flameproof, then the cable gland being used is required to be a sealing gland (explosion-proof or Ex d as necessary). For flexible cord entering Ex e enclosures, an Ex e cord connector would be required.

4) *Certification of cable glands*: Unlike UL 2225 the Canadian standard CSA C22.2 No. 174 only includes certification for Class I cable glands. Cable glands can also be approved with methods of protection markings (Ex) per CAN/CSA 60079-0 for Ex e cable glands and CAN/CSA 60079-0 and CAN/CSA 60079-1 for Ex d cable glands without additionally meeting the requirements of CSA C22.2 No. 174.

C. IEC

1) *Selection of cable glands – general*: The cable gland is selected to match the cable diameter. The use of sealing tape, heat shrink tube or other materials is not permitted to make the cable fit to the cable gland. If a cable gland is to be used at an ambient temperature range different from -20 °C to 40 °C or an operating temperature higher than 80 °C this must be covered by certification documentation. Cable glands are designed in accordance with IEC 60079-0 and the other 60079 series standards as applicable and selection for use is per the requirements in IEC 60079-14. Table 4 provides information on the selection of gland type according to the enclosure type that it is being used with. Where mineral-insulated metal-sheathed cables are used, the requirement to achieve creepage distances shall be maintained by selecting a certified mineral insulated cable-sealing device.

Cable glands and cables need to be selected to reduce the effects of "cold-flow characteristic" of the cable. "Cold-flow" in cables is the movement of the cable sheath under the compressive forces created by the displacement of seals in cable glands where the compressive force applied by the seal is greater than the resistance of the cable sheath to deformation. Low smoke and fire resistant cables usually exhibit significant cold flow

characteristics. Cold flow could give rise to a reduction in the insulation resistance of the cable and, where reasonably practical, efforts should be made to prevent this by selection of suitable cable glands.

TABLE 4
SELECTION OF GLANDS, ADAPTERS AND BLANKING
ELEMENTS TYPE OF PROTECTION ACCORDING TO THE
ENCLOSURE TYPE OF PROTECTION [16]

Equipment protection technique	Glands, adapters, and blanking element protection technique			
	Ex d	Ex e	Ex n	Ex t
Ex d	X			
Ex e	X	X		
Ex i and Ex nL - Group II	X	X	X	
Ex i - Group III				X
Ex m, Ex o, and Ex q	Ex m, Ex o, and Ex q would not normally be applied to wiring connections. The protection technique for connections shall suit the wiring system used.			
Ex n except Ex nL For Ex nR	X	X	X	
Ex pxb, Ex pyb or Ex pzc	X	X		
Ex pD	X	X		X
Ex s	Only as allowed by the conditions of the certificate.			
Ex t				X
X denotes permitted use.				

It is also necessary for the required minimum ingress protection to be maintained. To do this, it may be necessary to seal between the cable glands and the enclosure, e.g. using a sealing washer or thread sealant.

The minimum requirement for enclosures is IP54. In order to meet this minimum requirement, threaded cable entry devices going into threaded cable entry plates or enclosures of 6 mm or greater thickness need no additional sealing between the cable entry device and the entry plate or enclosure providing the axis of the cable entry device is perpendicular to the external surface of the cable entry plate or enclosure.

2) *Selection of flameproof cable glands:* For flameproof enclosures, the cable entry system is required to be either (a) barrier cable glands in compliance with IEC 60079-1 and certified as equipment, or (b) cable glands complying with the requirements of IEC 60079-1, certified as equipment and combined with the cables complying with the requirements in IEC 60079-14 and with a minimum length of the connected cable of 3 m.

The minimum 3m length is intended to minimize the possibility of flame transmission/gas migration through the cable. Flame transmission is a valid concern that is not addressed in current standards for field installed cables and glands. IEC 60079-0 provides requirements for cable gland performance, for example, pressure testing, but testing is carried out using mandrels not cables, and these requirements do not include flame transmission. For cables used with flameproof cable glands that use clamping by the sealing ring (compression) and where flame propagation of the flame may occur through the interstices between the strands of standard stranded conductors, or between individual cores of a cable, special cable construction must be employed as means of reducing and preventing flame propagation.

IEC 60079-1 specifies the principal parameters for flameproof joints, but these requirements do not apply to cables inserted into an enclosure through a cable gland. IEC 60079-1 also requires enclosures with built-in cable entries to be tested together with the cables for the non-transmission of an internal ignition, but these requirements do not apply to separate cable glands, which are commonly used. IEC 60079-14 Annex E provides an informative test procedure to test for gas migration through cables.

Based on testing conducted by one of the authors with a European testing laboratory, cables used with compression type Ex d cable glands that meet IEC 60079-14 Annex E requirements also passed non-transmission of ignition tests. It was found that the 3m length provides an approximate 2X safety factor with respect to non-transmission of an internal ignition when using a compression type Ex d gland with cables that meet IEC 60079-14 Annex E testing.

3) *Connections of cables to equipment:* Cables are required to be connected to the electrical equipment by means of cable glands appropriate to the type of cable used and need to maintain the explosion protection integrity of the relevant type of protection.

Cable glands shall be installed in a such a way so that after installation, they are only capable of being released or dismantled by means of a tool. If additional clamping is required to prevent pulling and twisting of the cable transmitting the forces to the conductor terminations inside the enclosure, a clamp shall be provided, as close as practicable to the gland along the cable. Cable clamps within 300 mm of the end of the cable gland are preferred.

Cables shall be routed straight from the cable gland to avoid lateral tension that may compromise the seal around the cable. When braided or armored cables have been terminated within the cable gland, the body components that are intended to retain and secure the cable braid or armor should not be able to be released manually or opened by hand without the use of a tool.

4) *Certification of cable glands:* The general design, testing, and certification requirements for IEC Ex cable glands are given in IEC 60079-0. All of the requirements for cable glands marked Ex e are located in IEC60079-0 [17], and there are no additional requirements in IEC 60079-7 [18]. There are additional requirements for cable glands in the following standards:

- IEC 60079-1 Cable glands for flameproof enclosures [19]
- IEC 60079-15 Cable glands for restricted breathing enclosures [20]
- IEC 60079-31 Cable glands for dust protection by enclosure [21]

Threaded cable glands can be tested and certified as Ex equipment cable glands or as Ex components. Non-threaded cable glands can only be certified as Ex components or included as part of the certificate for the complete equipment.

Ex d (flameproof) cable glands are required to meet IEC 60079-0 Annex A, IEC 60079-1, Clause 13.4 and IEC 60079-1 Annex C. Together with the enclosure, the cable glands shall meet the specified joint widths and gaps. The cable entries are only subjected to a pressure test of 30 bar. Thus, with a safety factor of 1.5, the cable entries can only be used if the maximum explosion pressure, (reference pressure), does not exceed 20 Bar. If the reference pressure is higher than 20 bar, the cable entry shall be tested together with the equipment (for example large flameproof motors). [22]

V. CONCLUSION

While all three of the electrical safety codes discussed are considered safe in their respective markets, there are significant differences between the cables permitted in hazardous locations. Of the three systems, the NEC requirements appear to be the most restrictive. Cable allowed for use in Class I Division 1 and Zone 1 is limited, with a few exceptions, to type MC-HL, ITC-HL, and TC-ER-HL under special conditions. CEC requirements permit any HL rated cable and cable certified to CSA C22.2 No. 174, to be used. While, for the most part, this has been limited primarily to the usage of TECK-HL in Canada the recent edition of the hazardous location cable standard, CSA C22.2 No. 174, lists ten different cable types that could be tested, certified and marked as HL.

The IEC appears to be the least restrictive, allowing any cable type to be used provided it meets some basic construction requirements. This should not be looked at in isolation though. Firstly, there are other rules in IEC60079-14 providing some basic construction needs for cables, providing some rules to protect cables in the installation and providing guidance to help mitigate the possibility of gas migration or flame propagation. There is, however, no mandatory testing of cables for gas migration or flame propagation. Tests provided in IEC 60079-14 are informative only. Secondly, IEC 60079-14 is not normally looked at in isolation. Installers are often required to have knowledge of other IEC 60079 series standards and have the competency to apply this knowledge in their installation where needed. There are many similarities in the requirements for cable glands between the IEC, NEC, and CEC, however, a number of significant differences also exist. First, because of the dual methods of classifying areas in the NEC and CEC, there exists an additional set of standards available for cable gland certification. These other standards allow for legacy cable gland usage and cable glands certified to

these legacy standards still dominate the North American market, whether being used in Zone or Class/Division classified locations. Additionally, the US uses the UL 2225 standard for the certification of all cable glands, including those marked with AEx d or AEx e. Canada, on the other hand, only uses CSA C22.2 No. 174 for the certification of cable glands marked Class I. In Canada cable glands marked with a method of protection, e.g. Ex e or Ex d, are approved per the CAN/CSA C22.2 No. 60079 series of standards and do not need to comply with CSA C22.2 No. 174.

Another significant difference is in the type of Ex d gland that can be used in some applications. In installations to IEC 60079-14, Ex d compression type glands meeting some conditions can be used for flameproof enclosures. While there is no normative requirement to do so, it is recommended to test cables that are used with compression type Ex d cable glands, to the requirements of IEC 60079-14 Annex E. Tests conducted by one of the authors indicated that approximately 60% of commonly used cables failed the Annex E tests. The study also showed that cables passing the Annex E testing also passed non-transmission of explosion tests carried out. It is possible to obtain approval as Ex d for a non-barrier gland or obtain Class I approval for a compression gland per CSA C22.2 No. 174. However, the installation codes in both Canada and the US require the use of seals and would not permit compression glands to be used unless they were used in conjunction with a seal.

The electrical industry in North America is slow to change with respect to permitting new equipment types and cable types for hazardous locations. Eventually though, evidence illustrating the safety of other cable and cable gland usage may lead to further allowances for cables and cable glands other than those currently existing in Electrical Codes today.

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VII. VITAE

Brian Keane is the Technical Resources Manager for Eaton in Mississauga, ON Canada. Brian joined Eaton through its acquisition of Cooper Crouse-Hinds and has worked there since 1989 in various manufacturing, product design, and application and Code support functions. He is a graduate of Ryerson University with a Diploma in Metallurgical Technology (1984) and a B.Tech in Industrial Engineering (1987). Brian is an author of several papers presented at PCIC, PCIC Europe, IEEE Megaproject and Safety Workshop as well as papers at other Hazardous Location Equipment conferences. He is Vice-Chair for the Integrated Committee for Hazardous Locations and a member of the Subcommittee for Section 18 of the CEC, the Canadian Subcommittee for IEC TC31 and several IEC TC31 maintenance teams and working groups. Recently Brian acted as Chairman for the task force responsible for updating CSA C22.2 No. 174

Gerhard Schwarz studied electrical engineering in Mannheim with the degree "Master of Engineering". For more than 40 years, he has been involved in sales, product management and designing of products to be used in hazardous areas. Up to the end of 2011, he was responsible for R & D Explosion protected light and switchgear in Cooper Crouse-Hinds GmbH and responsible for the worldwide certification of hazardous area products. In 2012, he was working as senior technical consultant inside Cooper Crouse Hinds for all general questions related to explosion protection, R&D, and certification. In 2013, he started a consulting company in the field of explosion protection. Up to the end of 2017, he served as Chairman of the German Committee "Electrical equipment for use in hazardous areas" in DKE, the German standardization association. He also served as Chairman of the of the working Group "explosion protected apparatus" in ZVEI, the German manufacturer association. He was Convener of the IEC TC 31 WG 40 Working Group luminaires, and Head of the German delegation in CLC TC 31 and IEC TC 31. He is involved in numerous CLC and IEC standards committees for electrical products to be used in hazardous areas, such as flameproof, increased safety and intrinsic safety. Also, he is working as German expert in the IEC MT 60079-14 Maintenance Team on Electrical installations design, selection and erection.

Peter Thurnherr studied mechanical engineering, electrical engineering and business administration in Basel and has a B.Sc. diploma. Thuba Ltd, which was founded in 1932, has been manufacturing explosion-protected electrical equipment since 1955 and he has been in full charge of the company since 1977. His field of work is in the design and production of electrical equipment for use in explosive gas and dust atmospheres in all types of protection. He led his company to be an accredited Inspection Body (SIS 145) for installations in hazardous areas. He is the chairman of the Technical Committee TC31 in Switzerland, a member of the international TC 31 working groups and maintenance teams General Requirements IEC 60079-0, Increased Safety IEC 60079-7, Non-Sparking IEC 60079-15, Risk of Ignition of Optical Radiation IEC 60079-28, Trace Heating IEC 60079-30-1 and IEC 60079-30-2, Inspection and Maintenance IEC 60079-17 and the convener of "Electrical installations design, selection and erection" IEC 60079-14.