The case for MICC Cables

White papers

Written by Richard Hosier and Geoff Williams

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Fire Resistant Cables

White Paper

Evolutions for testing fire rated cables and alignment with real fire scenarios

April 2014 rev 11042014

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Synopsis

The evolution of testing protocols for fire resistant electrical cables in many countries has led to a significant divergence between fire performances required and mandated for electrical cables and the different fire performances required for all other building structures, wall, fire-doors, penetrations, components and systems.

IEC 60695-1-10 states that fire resistance tests are developed to assess functional properties of a product or system under specified fire, heat or temperature conditions over a period of time and that to relate the findings of such tests to any real fire scenarios will require very careful consideration due to the effect of any uncontrolled variables such as the environment in which the product is used.

The common understanding amongst most specifiers, sellers, installers and users of fire resistant cables is that the products they buy and use will provide a level of electrical circuit integrity performance in emergency fire conditions for a time commensurate with the testing procedure in order to maintain functionality of the equipment connected.

This paper explores the differences in test methods which have evolved and questions if the methodology used in testing and qualifying electrical cables for fire resistance, is today appropriately aligned and representative with real fire scenarios which are likely to be experienced.

A short history

The first cable ever to be considered for fire survival applications was a Mineral Insulated design originally employing one or a combination of pulverized glass, siliceous rocks or asbestos as the dielectric. This design was patented by Swiss inventor Arnold Francois Borel in 1896. Subsequently the French company Societe Alsacienne de Construction Mechaniques (which subsequently became Cablerie de Lyon) did much of the development work to produce the product we now know today as Mineral Insulated Metal Sheath (MIMS) cable. Commercial production started in 1932 for applications with high safety requirements on ships and oil tankers as well as for critical installations such as in the Louvre museum. In 1937 the British company Pyrotenax purchased the patent rights and also began production.

Whilst certainly the best technical solution for circuit integrity and overall fire safety, mineral Insulated cables do require a different approach to installation. Different tools and fittings need to be used for terminating the cables as the mineral insulation (magnesium oxide as commonly used today) can be hydroscopic which can lead to a reduction in insulation resistance at cut cable ends if left in high humidity environments for long periods un-terminated. (This is effect is removed during the normal termination process). Due to the solid conductor design and compacted mineral insulation, larger cables tend to be more rigid so the installation time can be perceived by some installers to be longer than for plastic flexible cables. This situation lead to a desire from the market for cable manufacturers to design a and supply a more flexible cable with an installation methodology much the same as for conventional plastic cables but which could pass the cable flame tests of the day.

The first commercial designs for a flexible fire resistant electrical cable were constructions using copper conductors insulated with silicone rubber and provided with an overall glass braid. In flame tests at nominal voltages of 240/415 this design proved effective because as the silicone rubber degraded in the flames, the remaining ash had sufficient dielectric withstand to maintain functionality at the testing voltage. The down side to these designs was always the rather delicate mechanical structure of the ash which often cracked and crumbled during testing causing failure. The test method used at the time was a horizontal gas ribbon burner, where tests showed some short samples of this cable design could survive flame temperatures of 750°C for periods of up to 3 hours or more (beyond this the copper conductors would progressively become more brittle and mechanically unreliable due to oxidization). Just why 750°C was chosen is most likely a result of this being the temperature of the test flame used rather than any real simulation of a building fire scenario.

This cable design did have its limits however, as the residual silicone rubber ash, left after the initial degradation in the flame, was not physically strong and movement, vibrations or even the weight of the copper conductor in larger cables could crush the ash resulting in failure. Regardless the test method as used was ultimately adopted and standardized in 1970 as IEC331 with a proviso to limit the diameter of the cable under test to 21mm diameter due to practical limitations of the test setup itself.

During the 1970's cable manufacturers started to introduce new designs of cables based on glass-mica tape (GMT) wrapped conductors with ethylene propylene rubber (EPR) or polyethylene (PE/XLPE) insulations. These constructions also proved capable of surviving the flame test to IEC331:1970 however in comparison with the early Silicone rubber insulated cable construction, the GMT cable designs often exhibited more consistent performance in fire tests when subjected to movement, vibration and even some water spray (as might be expected from fire sprinklers or fire-fighting efforts). Today, some manufacturers produce fire rated cables using improved silicone rubber insulations, which will still form a brittle ash but may also provide more consistent results in testing.

British Standards adopted the basic IEC331 test method in BS6387:1983 but included an allowance for increased flame temperature to 950°C (test C) and included 2 additional tests: 15 minute fire with mechanical shock (test Z) and 15 minute fire with water spray (test W) which were intended to simulate the anticipated disturbance to electric cables by deformation of mountings, supports, falling debris as well as water spray. Perhaps strangely, each of the three tests are not required to be conducted on the same piece of cable as would be expected in a real fire but allowed to be conducted on fresh samples of new cable.

The IEC331:1970/IEC60331:2009 and BS6387CWZ flame test methods are today widely adopted in many countries around the world as a common test method for fire resistant electrical cables.

The situation today:

Since the publication of these standards, many hundreds or even thousands of cable manufacturers around the world have adopted Silicone Rubber and/or Glass Mica Tape (GMT) cable designs in order to produce cables to meet IEC 60331, BS 6387CWZ and other test methods. Some more advanced manufacturers have additionally modified silicone compounds to try and improve the strength of the ash residue or developed new ceramic based compounds which in testing can provide more consistent performances in fire tests.

Running parallel to these cable design evolutions have been several incremental enhancements to electrical cable flame test standards and application standards, especially in the United Kingdom:

BS 6387:1994	Performance requirements for cables required to maintain circuit integrity under fore conditions. (now withdrawn with revision 2013)
BS 7629: 1997	Parts 1 & 2: Specification for 300/500V fire resistant electric cables: (BS7629-1 was reissued in 2008, it superseded BS7629-1:1997 and BS 7629-2:1997 which have been withdrawn)

BS EN 50200: 2000 Method of test for resistance to fire of unprotected small cables:

PH30, fire temperature 850°C 15 min. then further 15 min with mechanical shock and water spray.

PH120 fire temperature 850°C, 60 min. then further 60 min. with mechanical shock and water pray.

(BS EN 50200: 2000 is now replaced by BS EN 50200:2006)

BS7846/F2: 2000 0.6/1kV armored fire resistant cables:

(adopts test protocols of BS 6387 for cables up to 20mm diameter)

Cat C = fire temp. of 950°C for 3 hours

Cat W = fire temp. of 650°C for 15 min then water spray 15 min

Cat Z = fire temp. of 950°C for 15 min with mechanical shock

BS 5839 - 1: 2002 Clause (26.2 d&e) Fire detection and alarm systems for buildings:

Included additional testing for “Enhanced” fire performance testing.

BS8434-1:2003 Method of test for resistance to fire of unprotected small cables:

(Similar to BSEN50200 with addition of water spray)

Fire temperature 850°C 15 min with mechanical shock then 15

min with mechanical shock plus water spray. (Now withdrawn as test has been incorporated into BS EN50200 with Annex E)

BS8434-2:2003 Method of test for resistance to fire of unprotected small cables:

Fire temperature 930°C for 60 min with mechanical shock plus an additional 60 min at 930°C with mechanical shock and water spray. (Similar to BSEN50200 but with modification of flame temperature to 930°C and water spray for final 60 minutes)

BS7346-6: 2005 Components for smoke and heat control systems – Specification for cable systems: LS 30 (minutes), LS60, FF120

(Tests protocol identical with BS8491:2008. This standard is now withdrawn with the publication of BS 8519:2010.

BS EN 50200: 2006 Method of test for resistance to fire of small unprotected small cables for use in emergency circuits.

PH15 (minutes), PH30, PH60, PH90, PH120 with flame temperature at 850°C for the required duration with mechanical shock every 5 minutes. An optional fire with water spray test may be applied with fire and shock for 15 minutes then fire with shock and water spray for the last 15 minutes of the testing.

BS8491:2008	Method of assessment of fire integrity of large diameter power cables: Fire temperature 850°C for 115 minutes with direct mechanical shock on the cable and then water jet for 5min.
BS8519:2010	Selection and installation of fire-resistant power and control cables for life safety and fire-fighting applications. (Adopts test methods to BS EN50200:2006 or/and BS8491:2008 for 30 minutes, 60 minutes or 120 minutes fire survival time)
BS 6387:2013	Test method for resistance to fire of cables required to maintain circuit integrity under fire conditions. Consists now of only three component protocols designated C, W and Z. (test methods unchanged from 1994 edition) Categories A, B, S, X and Y are now obsolete. Includes clauses 6.4, 7.4, 8.4: If the first test sample fails in test, two further samples can be tested and if both these samples pass the cable shall be deemed to have passed the test.

In common for all the test methods developed above **(**which have been subsequently adopted by various standards authorities and in turn mandated by some Authorities Having Jurisdiction (AHJ)**)** is that they have been developed especially and independently for electrical cables. The tests have evolved based not on any real full scale building fire scenario but on the flame resistance performance achievable with specific electrical cable designs. In contrast, where fire resistance is required in buildings for structures, penetrations, fire doors, fire windows, fire partitions, fire rated floors, walls etc., the fire resistance test methodology follows the time temperature regime of **The Standard Time Temperature Curve** (ISO 834-1) on full scale test samples and this fire test differs significantly from the flame only testing protocols used for electric cables on short representative lengths.

For testing electrical cables one important difference which must be recognized is that it is necessary to test the electrical integrity as well as the mechanical integrity of electric cable system under real fire conditions (to ensure the critical life and property saving, fire prevention, fire-fighting, evacuation and communication systems remain operational) whereas with structures and other construction products it is only the physical integrity of the full scale sample which needs fire testing. Whether the existing lower temperature and simpler “flame only” test methodology used for electrical cables is appropriate for these two testing objectives, or if the same test protocol as used for fire testing every other building element would be more appropriate is an interesting and unanswered question.

The Standard Time Temperature Curve

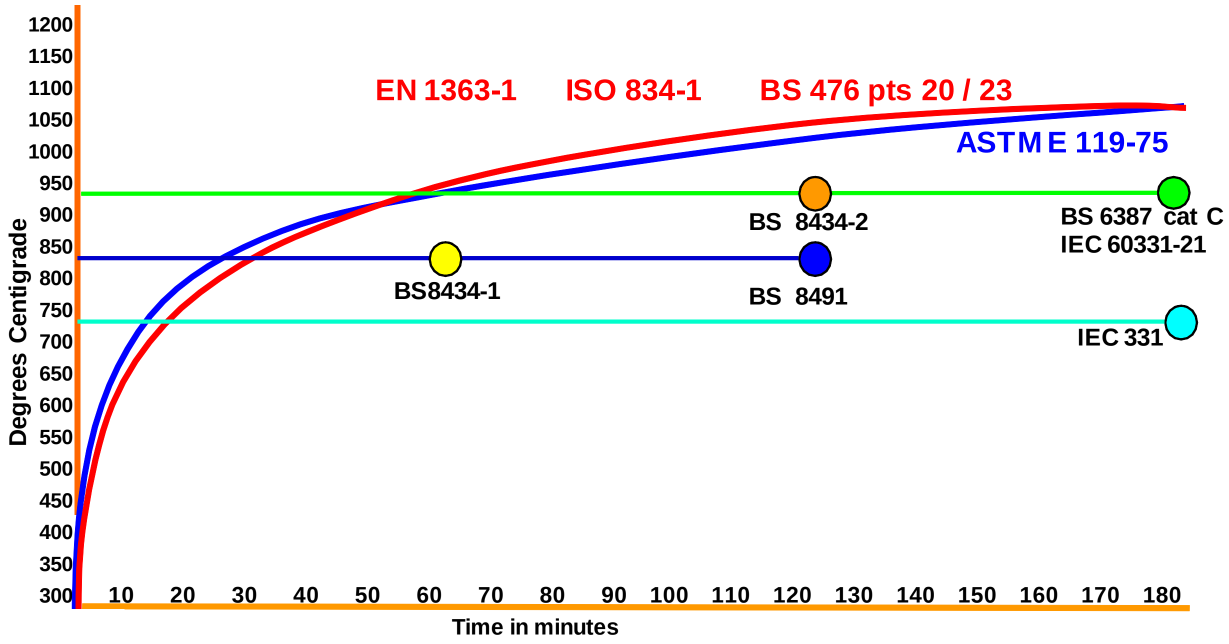
A Standard Time / Temperature Curve was published in 1918 through conferences amongst eleven North American technical societies and organizations called jointly by the American Society for Testing Materials (ASTM) committee on fireproofing and the National Fire Protection Association (NFPA committee on fire resistive construction. In arriving at the standard a dozen different rate of rise curves were considered.

The committees developing the standard drew on the guidance given from the International Fire Prevention Congress held in London in July 1903 and the measurements of furnace temperatures made in many fire tests carried out in the UK, Germany and the United States. The tests were described in a series of “Red Books” issued by the British Fire Prevention Committee after 1903 as well as those from the German Royal Technical Research Laboratory. The finalization of the ASTM standard was heavily influenced by Professor I.H. Woolson, a Consulting Engineer of the USA National Board of Fire Underwriters and Chairman of the NFPA committee in Fire Resistive Construction who had carried out many tests at Columbia University and Underwriters Laboratories in Chicago. The small time temperature differences between the International ISO 834-1 test as we know it today and the America ASTM E119 / NFPA 251 tests likely stemmed from this time.

The curve as we see it today (Pic 1) has become the standard scale for measurement of fire test severity. When elements, structures, components or systems are tested, the furnace temperatures are controlled to conform to the curve with a set allowable variance and consideration for initial ambient temperatures. The standards require elements to be tested in full scale and under conditions of support and loading as defined in order to represent as accurately as possible its functions in service.

When comparing the simple flame only testing protocols used for testing resistance of electrical cables as described in the initial paragraphs above to the fire testing protocols used for the other fire rated components of the building and its structure, it is interesting to note that two fundamentally different methods are employed: Tests on electrical cables are today primarily flame tests using a ribbon gas burner on one side of a short length of cable whereas tests for building structures, fire doors, fire windows, penetrations, fire rated walls, floors, glass etc. are tested to a fire test protocol which is an oven test using a full scale sample. This test completely envelopes the components being tested; as described in BS 476 pts 20 to 24, ISO834-1, EN1363-1 and AS/NZS 1530pt 4.

Of particular note is the fact that the flame test protocols for electric cables (IEC 60331, BS6387, BS/EN50200, BS8434, BS8491) start and finish at a uniform temperature and are generally rather lower than the final oven test temperatures used for fire testing all the other fire rated components of the building and its structure.



Pic 1

Logical questions to ask might be: “Why is it that the test methods used for **flame** testing of electric cables in the UK and most parts of Europe and as adopted so widely around the world, vary so much from the **fire** test methods for the other fire rated building components and structures?” and “Why should electric cables be tested differently and often at lower final temperatures?” It would seem these questions need more investigation given that electrical cables in practice may be exposed to the same fire time temperature conditions.

It is the mandate for standards organizations to write standards based on minimum performance requirements. It is therefore both rational and crucial that for Fire Resistance electrical cables the minimum performance would have to be operational function under the same terms and duration as all the other fire rated structures and systems and this is the standard time temperature protocol of ISO834-1 aka BS476 pt. 20 to 24, EN1363-1 and AS/NZS 1530pt 4. Any additional performance enhancements such as fire with water and fire with direct mechanical impact (especially when usually conducted at lower temperatures) should at best be supplemental test requirements or be seen more as product features of individual manufacturers. After all no other fire rated structure or system like fire rated doors, walls or glass partitions are required to undergo such water or direct mechanical impacts and their integrity during fire is equally important.

What do other developed countries require?

Interestingly this apparent testing anomaly is not the same in all countries. In Germany, Belgium, Australia and New Zealand the fire test time temperature protocol required for qualifying fire resistant electric cables is the same as used for all other fire rated building structures, systems and components. This is the standard time temperature curve of ISO 834-1, EN1363-1 and adopted by AS/NZS 1530pt 4. In America and Canada fire resistant electric cables are also required to be tested to the same time temperature protocol as all other fire rated building components and structures, this is ASTM E119 / NFPA 251. It is perhaps not entirely surprising that the time temperature protocol of the American testing is remarkably similar to the European ISO834-1, EN1363-1, BS476, and AS/NZS1530pt4 curves. Both are full scale oven tests.

Fundamentally the difference between **flame** and **fire** test protocols is that the **flame** tests as used for electric cables in UK, many parts of Europe and the world may be more representative of the early and pre-flashover period of a fire development where oxygen is both plentiful and available and temperatures are lower. Post flashover fire environments tend to be quite different and are more accurately represented by oven fires where oxygen levels drop and fire temperatures rise quickly to high levels.

The most common installation of electrical cables is where they are mounted and attached to cable tray or ladder, run in conduits or clipped direct to non combustible walls. In BS6387CWZ, BSEN50200, BS8434 part 2, the cable samples for testing can be mounted on a non conductive backboard with earthed mounting clips (but often insulated). In BS8491:2008 the cable where subjected to flame is not mounted on a support and hangs freely in air bent at the cables minimum bending radius. It is at best debatable if these test installations and test conditions are representative of full scale common and real world installation environments.

In the test methods of Germany's DIN 4102-12, Australia & New Zealand's AS3013:2005 and America's UL2196 electrical cables are required to be mounted direct, or on earthed metal cable tray or in earthed steel conduit including bends and secured as the circuits would be installed in real building installations. This test regime is intended to simulate the bending, deformation and mechanical stresses on both the cable and the metallic supports and fixings as a result of the furnace heating which in turn reflects the stresses imposed on the cables attached thereto. Subsequently the cable, supports and fixing are then classified as a 'cable system' not just a cable alone. In addition, both the Australian test and American test have a provision for demonstrating resistance to water spray after up to two hours exposure to the fire which imparts the maximum damage to the cable system before assessing its ability to remain watertight.

In the UK the new BS8519:2010 is published as a form of guidance to identify a cascade basis for fire protection of all circuits supporting life safety and fire fighting systems and includes amongst others, a 'cable system' approach addressing the installation practice inclusive of supports and fixings for essential circuits requiring circuit integrity in case of fire.

What do the building codes and authorities having jurisdiction say:

A review of various countries building regulations including in the UK and the requirements of the respective AHJ's reveals that Standard Time Temperature test method is almost exclusively the required test protocol to determine fire resistance of building structures, components and systems:

Compartment wall

BS 476 Pt 4/11 or Pt 6 & 7 and

BS 476 Pt 22, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251

Protected shaft enclosing lift

BS 476 Pt 4/11

BS 476 Pt 20, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251 and

BS 5588 Pt 5 App A & BS 5234 Pt 2 and4.BS 1230 Pt 1 (gypsum plaster board) or ISO 1896 (calcium silicate or cement board)

Protected shaft enclosing staircase or services

BS 476 Pt 4/11 and

2. BS 476 Pt 22, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251 and

3. BS 5588 Pt 5 App A & BS 5234 Pt 24. BS 1230 Pt 1 (gypsum plaster board) or ISO 1896 (calcium silicate or cement board)

Fire-rated Floor

1. BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 21, AS 1530 Pt 4 or ISO 834

Protection to steel beams that support RC floor

BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 23, AS 1530 Pt 4 or ISO 834

Protection to timber/ steel flooring

BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 21, AS 1530 Pt 4 or ISO 834

Protection to steel structure

BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 21, AS 1530 Pt 4 or ISO 834

3. BS 1230 Pt 1 (gypsum plaster board) or ISO 1896 (calcium silicate or cement board)

Protection to building services i.e. cables, sanitary pipes, chilled water pipes etc

BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 20/24, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251

Fire-rated Ventilation, Smoke-extraction and/or Kitchen Exhaust Ducting System

BS 476 Pt 4/11 or Pt 6 & 7 and

2. BS 476 Pt 24, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251

Fire Stopping Material

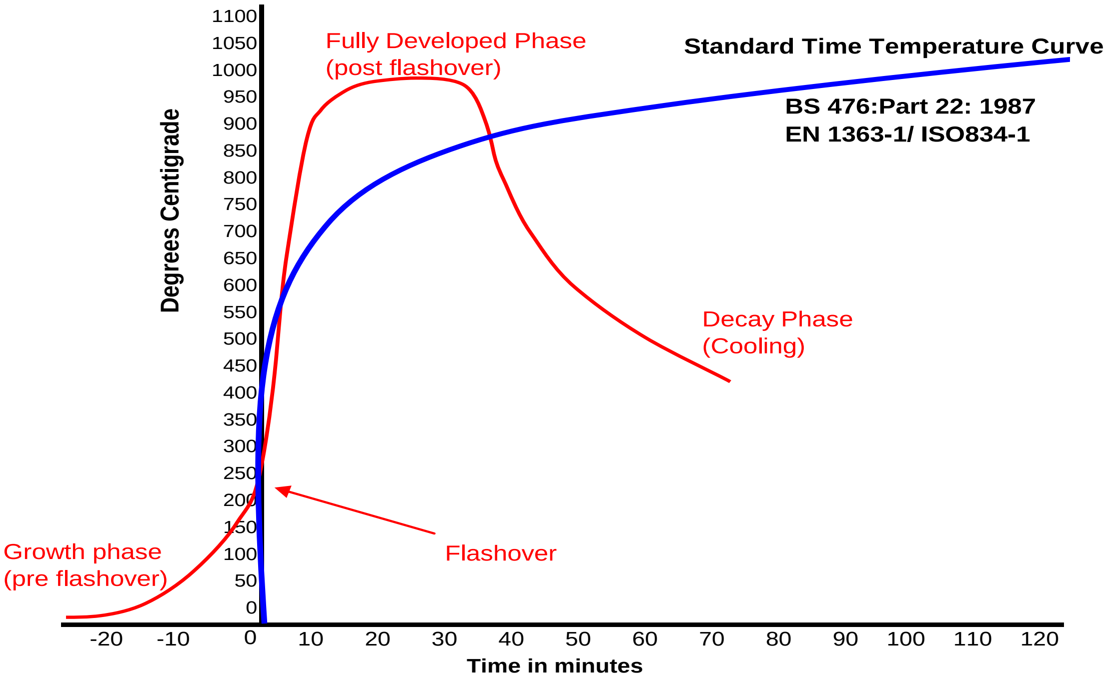
BS 476 Pt 20, AS 1530 Pt 4, ASTM E119, ISO 834 or NFPA 251

Flame tests, Fire oven tests and real fires:

The objective of testing is to simulate environments in order to establish a likely performance level. In fire testing it is impossible to simulate every possible scenario so some form of compromise is needed. There are always arguments on whether a more sever fire environment should be set as the test norm, a lesser fire or a more averaged fire environment. Forensic evidence after many fires can determine the fire severity experienced and as can be expected, these will vary considerably with the environment, location, fuel source and fuel quantity.

The BS 476, ISO 834-1, EN 1363-1, AS/NZS1530 pt 4 time temperature curve plotted

against a real fire curve (depicting room temperature), showing point of flashover.



Pic 2

As can be seen from Pic 2, real fire temperatures rise very quickly after the point of flashover and in cellulosic above ground environments like buildings, offices, houses etc. the oxygen levels near the fire source will drop. Fire temperatures reached and duration will be dependent on the fuel source and quantity plus the air / oxygen conditions. In the growth phase (pre-flashover) the actual flame temperatures initiating the fire will typically be around 600°C to 900°C but the surrounding room temperatures will only rise more slowly. It is only when the overall room temperature reaches the point where spontaneous combustion of other flammable items that flashover occurs. The room temperatures then rise very quickly.

Although the two curves in pic 2 do not appear to be very similar, they both exhibit similar characteristics in that the room temperature starts low, rises quickly over a few minutes and experiences reducing oxygen levels. Testing by definition needs to be both consistent and repeatable in order to determine comparative performances. The Standard Time Temperature Curve (European and American) has demonstrated over many years to be both consistent and repeatable at many test institutions in the UK and around the world.

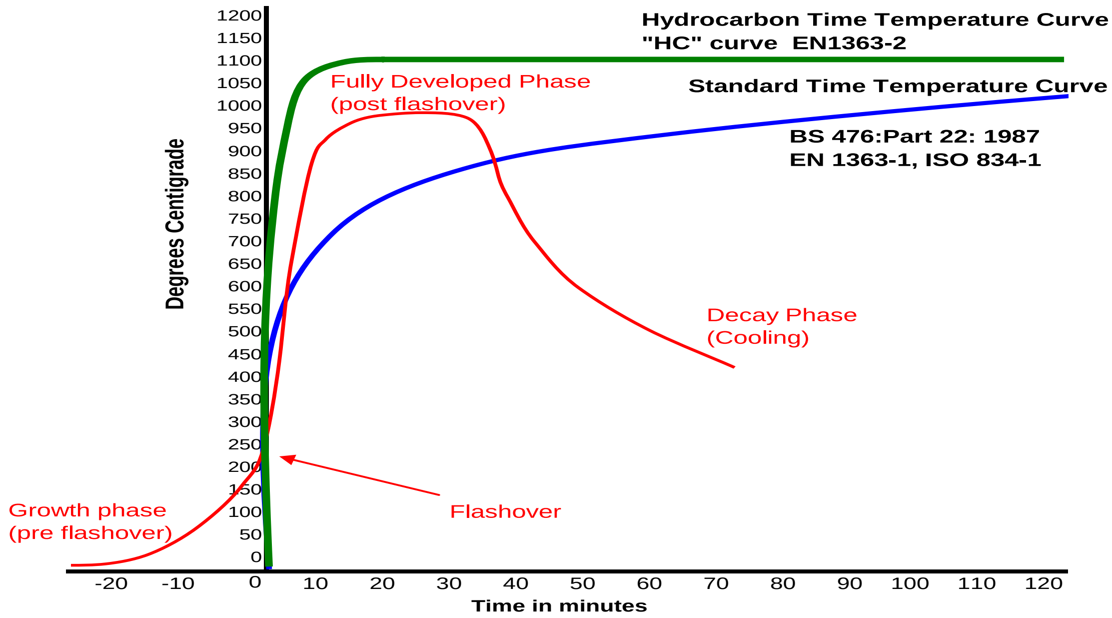
Are all Fires the same?

As mentioned earlier in this paper, fires are not all the same. Differences in fuel source, fuel quantity, environment, air flow/availability will all affect the real fire profile. Whilst the Standard Fire Time Temperature curve is intended to depict with a reasonable accuracy and repeatability most common fire scenarios in domestic and commercial building environments, we also well know that fires involving Industrial and Petrochemical installations, Offshore vessels, in tunnels and underground environments can exhibit far more serious scenarios and in such cases the Standard Fire Time Temperature curve is often not optimal.

For more enclosed environments such as in road, rail, pedestrian tunnels, underground car parks, underground shopping malls, or other similar enclosed environments, the fire generated heat is often not able to escape as easily as it might in above ground cellulosic buildings. Smoke and heat build-up can be more rapid and from both experience and from testing it is shown that the resulting fire temperatures can often reach levels well in excess of those experienced in above ground buildings and in far less time.

A more severe test was developed in the mid-1970's for the testing of selected components for use on offshore installations by J.H. Warren, A.A. Corona and R.G. Gowar which was carried out with tests using hydrocarbons. This work was further developed by the Mobil Oil Company who conducted pool pit fires in the Arizona desert and from this the Hydrocarbon Curve or "HC" curve was developed. In the mid 1980's Lloyd's Register (LR) introduced a "H" rating for mobile offshore installations. Initially this was a "H-60" rating (60 minute rating) although the requirement was increased to 120 minutes due to the amount of fuel which was anticipated to be available in such offshore installations.

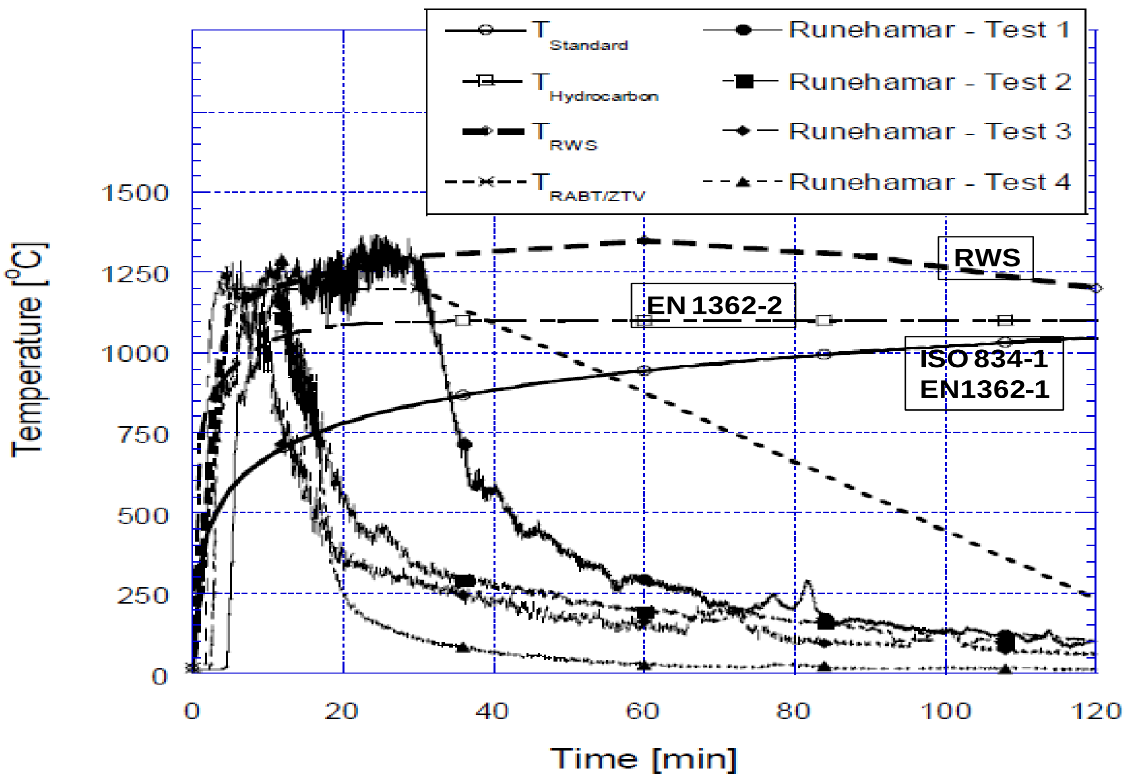
Following the adoption of the Hydrocarbon test by the Norwegian Petroleum Directorate, the Canadian Newfoundland Petroleum Board, Australian and Danish authorities, a fire test standard known as ASTM E1529-93 was developed for determining effects of large hydrocarbon pool fires on structural members and assemblies. Subsequently a number of standards organizations have now introduced a hydrocarbon time temperature curve, namely ISO 834 (HC) and BS 476 pt 20/21 appendix D, AS 1530 pt 4 Appendix D and ANSI/UL 1709 in USA.



Pic 3

Based on full scale fire tests carried out in Tunnels utilizing road vehicles including passenger cars, busses, trucks with different loads and rail vehicles including Intercity and Metro/Underground carriages, it has been well established that in enclosed tunnel environments fire temperatures exhibit a very fast rise time and can easily reach temperatures well above the parameters of the standard ISO 834-1 curve.

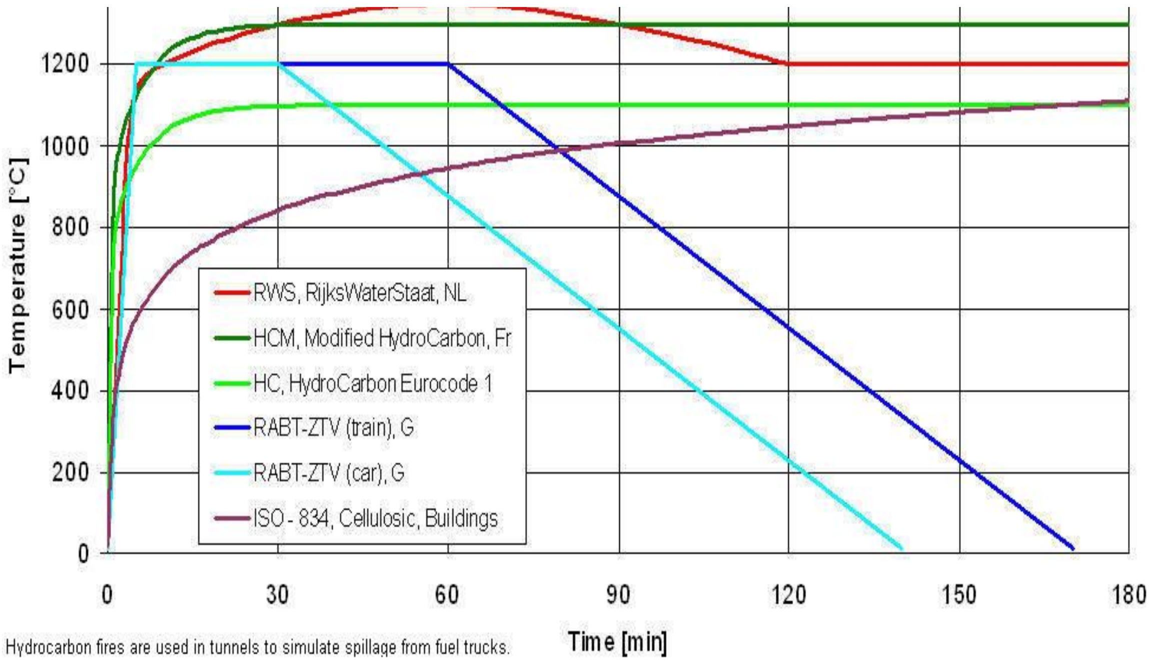
Time temperature profile of tunnel fires of HGV trailers with different cargo.



Haukur Ingason and Anders Lonnermark of the Swedish National Testing and Research Institute presented a paper at the First International Symposium in Prague 2004: Safe & Reliable Tunnels

Different time temperature curves have now been developed and adopted for tunnel applications such as the RABT/ZTV tunnel curve in Germany, a modified HC curve for some category of tunnels in France and even the very stringent Rijkswaterstaat tunnel curve (the RWS curve) in the Netherlands. These tunnel curves are often used but are not required by all authorities or tunnel owners. One reason for this is that for such extreme temperature situations as the RWS curve, a large fire scenario is required which may be considered by tunnel designers as an unlikely or extreme event outside the design criteria for the tunnel. (Tunnel fires such as St Gotthard in Switzerland with 11 dead, Jungjango Metro fire in South Korea with 189 dead may contradict this assumption). Economic considerations also unfortunately often come into play as costs to protect a tunnel from major events could make many tunnel projects financially unviable.

International Time/Temperature Curves used to test the fire-ratings of passive fire protection systems in tunnels and buildings



Pic 4

In America NFPA 502:2008 edition, clause 11.4.2 now requires that for limited access highways in the USA the construction and structure including the electric cables need to be protected in order to survive fire temperatures in accordance with the RWS curve (60 minutes for electric cables of emergency circuits). Other tunnels authorities and countries are moving towards a more pragmatic adoption of the Hydrocarbon Curve (HC) for tunnel and underground applications based on realistic and anticipated fire scenarios as well as tunnel economics. In these underground applications it would seem even the Standard Fire Time Temperature test is inappropriate let alone the simple low temperature flame tests used for electric cables in many countries.

Conclusions

Whilst most underground fire testing and simulations have been conducted for Road and Rail tunnels, a basic fact is that most underground or enclosed environments will likely exhibit similar or worse fire characteristics as found in tunnels. This means that for underground car parks, underground shopping centers and enclosed environments, especially where a significant static fire load exists along-side significant temporary fire loads (as in underground shopping centers), the question of possible fire scenarios and subsequently the construction fire resistance requirements for structure and components (including exposed electrical cables) may require reconsideration beyond the current time temperature parameters of BS476, ISO 834-1, EN1364-1 and far beyond the current flame test protocols of BS6387 CWZ, IEC 60331 for electric cables or any of their more recent evolutions. This is also now recognized in the UK by BS 8519:2010 and highlighted in clause 20 “Areas of special fire risk”.

For cases in above ground and below ground environments, full scale fires are best replicated by furnace tests as described in BS 476, ISO 834-1, EN 1363-1, AS/NZS1530 pt 4 or in USA / Canada ASTM E119 standards. This is why the majority of physical building structures and construction components are required to be tested accordingly. It also make sense that exposed electrical cables which are designed to withstand and operate under fire conditions should be tested to at least the same fire time temperature test protocols as all the other physical fire resistant parts and components of the building.

It has been argued that not all installation locations for essential electrical circuits are run exposed and such cables suitably protected (such as with physical fire barriers or with conduit buried in concrete) should therefore be tested together with the protection. This argument may have some merit and is addressed in the Australian Standard ASNZS3013, although no such considerations are made for any other building structure, system or component. It is both logical and more important for Fire Resistant electrical cable circuits to be tested at an equal or even more stringent level given that they are active rather than passive systems needing to provide both electrical and physical integrity in order to ensure the effective reliable operation of both Life Safety and Fire Fighting systems.

Standards organizations and AHJ's have the task to set and mandate 'minimum performance' levels. Professional Engineers need to consider 'case by case' if such minimum requirements are appropriate or if more rigorous performances are needed. Simply adopting existing standards or norms may not absolve Professional Engineers in some jurisdictions from liability if it can be proven that the current minimum standards or norms were reasonably known to be insufficient for the application.

Manufacturers and suppliers of fire resistant cables need to recognize the need to provide cables designed to survive real fires and not just pass simple flame tests. Today, using new materials and cable construction technologies, many manufactures can provide a range of electrical cables which can pass the fire oven tests when installed exposed and when tested to the same fire resistant test protocols as are required for all the other the physical building structures, components and essential systems i.e: BS 476, IEC 834-1, EN1363-1, and AS/NZS1530 pt4 etc. (as is required for electric cable systems in Australia & New Zealand by AS/NZS3013-WS52W, Belgium and in Germany by DIN 4102-12). Interestingly many of the major cable manufacturers who sell cables in UK and Europe already make and sell these higher performing cables into countries where the Standard Fire Time Temperature testing protocol is required. These cables are however more expensive than the cheaper products designed only to pass some simple flame tests.

Today there are more and more constructions of tunnels, underground complexes such as basements, underground shopping malls, underground car parks, underground living and working areas, enclosed environments. These enclosed environments are well known to have increased fire risks so Consultants, Designers, Standards organizations and AHJ's may need to demand by specification that Cable suppliers provide electrical wiring systems capable of functional operation when installed exposed to the higher fire time temperature requirements of EN 1363-2, BS476 appendix D, AS/NZS1530pt 4 appendix D, better known as the Hydrocarbon Curve or "HC" curve or even the RWS curve as is required now in USA and Canada for wiring systems in for limited access highways such as Tunnels and Bridges.

TRM & MICC Ltd manufactures Mineral Insulated Cables with Copper or special metal alloys capable of meeting all known Fire, Flame and Oven tests. The company provides a guaranteed Fire Proof wiring system which is also

100% flame retardant, 100% Halogen free, 100% smoke free, 100% toxic emission free with zero organic content thus with no fuel element, no heat of combustion, no oxygen depletion and no contribution to temperature rise. No other cable design today can guarantee this, or provide the same level of overall fire safety and integrity security throughout the life of the building. In addition MICC cables are both water and oil proof, have a greater current ratings and have smaller diameters compared to other cable deigns. They require no conduit for mechanical, vermin or insect protection, need fewer fittings, are 100% UV, Ozone and sunlight resistant as well as radiation resistant, are non-ageing, will operate in cryogenic environments and are mechanically stronger than any other cable design in all operating or emergency conditions.

Unlike Polymeric FR cables, the cable characteristic impedance of MICC does not significantly change during fire (and especially water spray) thus ensuring reliable individual detector identification by the MFIB (as transmitted by the necessary higher frequency data transmission of modern addressable fire detection systems).

MICC cables are environmentally inert having no toxic or hazardous materials so during installation, service life and disposal the cables have a zero environmental impact and are fully recyclable.

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Australian Standard AS 1530pt 4 and Appendix D

British Building Regulations: 2000 (Effective April 2007)

British Standards BS476

Part 20 Fire Testing - General principals

Part 21 Fire Testing - Load bearing elements

Part 22 Fire Testing - non load bearing elements

Part 23 Fire Testing – contribution of components to fire resistance of a structure

British Standard BS8519:2010

Building Code of Australia: 2009

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Fire performance of Electric Cables

White Paper

Flame Retardance	**explained**
Smoke Obscuration	**explained**
Fire load & Heat of combustion	**explained**
Halogens and Toxicity	**explained**
Aging and Life Span	**explained**

May 2014

Contents

Synopsis

The common understanding amongst most specifiers, sellers, installers and users of fire performance electrical cables which are manufactured to meet the requirements of common fire Performance tests like: Flame retardance tests: Smoke obscuration tests, Halogen and acid gas emission tests is that the cables they subsequently specify, buy and use will provide a similar performance under real fire scenarios that the test methods suggest. Unless the cables are exposed exactly to the same conditions as documented in the test, which is unlikely, this may not be the case.

IEC 60695-1-10 states that fire tests are developed to assess functional properties of a product or system under specified fire, heat or temperature conditions over a period of time and that to relate the findings of such tests to any real fire scenarios will require very careful consideration due to the effect of any uncontrolled variables such as the environment in which the product is used.

It is not commonly known that electric cables constitute one of the biggest fire loads in many modern buildings, nor of the potential risks this might present. There are also many common misconceptions in the market concerning what constitutes fire safety especially as it relates to Halogens and Toxicity, Flame retardance, Smoke generation, Fire loads and associated oxygen depletion on combustion.

This White Paper takes a closer look at the standards, the cables and the conditions in which many electric cables might be exposed to fire. It explains and raises some serious concerns about common cable fire test methods and our understanding of these standards as they might relate to real fire scenarios.

Electrical Cables:

Flame Propagation & Flame Retardance

Electrical cables are frequently blamed by the media and fire authorities as the cause of many building fires which regardless if true or not, may not be a complete explanation. Often it is not the cable which starts a fire but the misuse of the cable by frayed or damaged insulation, overloading due to incorrect or insufficient circuit protection, short circuit or over voltage. Today with so many switch-mode power supplies 3rd order harmonic currents at higher frequencies can also cause overloading, including in neutral conductors. These situations can cause high temperatures in the cable conductors or electrical arcing which in turn heats the cable insulation and surrounding combustible materials to initiate a fire.

Irrespective of the root cause, cable manufacturers endeavor to manufacture electric cables which under the above situations or in cases where a fire is started by another unrelated cause, will not burn or at least will not propagate the fire through the building.

In UK and around the world there are now many cable flame retardance standards written by BS, IEC or others which propose test methods to determine if the cables are self-extinguishing, or as we like to say in the industry: “Flame Retardant”.

This article takes a new look at these tests and questions if the test methods employed and their subsequent adoption into BS, IEC and other standards, building codes and authority specifications do in fact provide the implied level of flame retardance performance when installed and used in buildings.

Making flexible electric cables:

Most common flexible cables are made from hydrocarbon based polymers. These base polymers are not usually flame retardant and have a high calorific value so chemicals are added to modify the polymers to make them more suited to electrical cable use. Halogens like Chlorine, Bromine, Fluorine are particularly good fillers which help retard flame propagation and don’t significantly impact the dielectric properties of the polymer so Halogens can be used in both cable insulations and in cable sheaths. These halogenated polymers (like in PVC or CSP) also have a negative effect in that during fire they release the halogens as halides which are extremely toxic and irritant.

For cables which need to be Halogen Free and Flame Retardant other non-halogen flame retarding elements such as alumina trihydrate (ATH) can be used instead of Halogens, but while effective in retarding flame propagation these fillers negatively affect the polymer in other ways such as reducing dielectric performance and affecting mechanical, chemical and water resistance. For this reason additives like ATH are mostly used only for cable jackets. Halogen Free Flame Retardant cables will most often use a more pure polymer like PE/XLPE or EPR for the insulation which has good dielectric and mechanical properties but are not very flame retardant.

Electric Cables: Propagation performance in Fire

Understanding the above we quickly realize that the best flame retardant cables often are halogenated because both the insulation and outer Jacket are flame retardant but when we need Halogen Free cables we find it is often only the outer jacket which is flame retardant and the inner insulation is not.

This has significance because while cables with a flame retardant outer jacket will often pass flame retardance tests when cables are subjected to an external flame, the same cables when subjected to high overload or prolonged short circuits have proved in university tests to be highly flammable and can even start a fire.

Whilst this effect is well known and published (8th International Conference on Insulated Power Cables - Jicable'11 – 19 – 23 June 2011, Versailles – France) it is perhaps surprising that not one international test method or standard exists for testing cables in such a seemingly common event as current overload and one cited by authorities and the media as a primary cause of building fires.

On evaluating the common flame propagation test methods, such as IEC60332 pt.1 & pt 3 BS 4066 pt. 1 and pt. 3 which employ an external flame source on a sample or samples of cable, it is further concerning that the test samples undergoing these tests are not pre-conditioned to operating temperature but tested at room temperature. This oversight is important because the temperature index of the cable (the temperature at which the cable material will self-support combustion in normal air) will be significantly affected by its starting temperature i.e: The hotter the cable is, the more easily it will propagate fire.

Certainly it would seem that Standards organizations and Authorities need to re-evaluate the current flame retardance test methods and standards which are commonly understood by Consultants and consumers alike to provide a reliable indication of a cables ability to retard the propagation of fire.

If we can't trust the Standards what do we do ?

Clearly where we have electricity with its inherent properties of voltage & current and cable conductors with their inherent property of resistance the result will be some heat. It is imperative that both cable insulations and jacket materials must be flame retardant to protect from external fire and protect from internal fire such as current overload or arcing.

In USA it is interesting to note that many building standards do not require halogen free cables. Certainly this is not because Americans are not wisely informed of the dangers, rather the approach taken is that: "It is better to have highly flame retardant cables which do not propagate fire than minimally flame retardant cables which may spread a fire". i.e. a small fire with some halogen is better than a large fire without halogens. One of the best ways to make a cable insulation and cable jacket highly flame retardant is by using halogens.

In Europe and as adopted in many countries around the world they adopt a different mentality: Halogen Free and Flame Retardant. Whilst this is an admirable mandate the reality is rather different: Flame propagation tests for cables as adopted in UK and Europe can arguably be said to be less stringent than some of the flame propagation tests for cables in USA leading to the reasonable conclusion that common tests in UK and Europe may simply be tests the cables can pass rather than tests the cables should pass.

Of course simply adopting UL and ASTM flame propagation tests instead will result in difficulties for many cable manufacturers to supply cable meeting these tests which are also Halogen Free. On the face of it a dilemma with no easy solution.

Conclusion

For most flexible polymeric or plastic cables the choice remains today between high flame propagation performance with Halogens and reduced flame propagation performance without halogens.

Whilst enclosing cables in steel conduit will reduce propagation at the point of fire, hydrocarbon based combustion gasses will propagate through the conduit to switchboards, distribution boards and junctions. Any spark such as the opening or closing of circuit breakers, or contactors is very likely to ignite the combustible gasses in the switchboard leading to explosion and spreading the fire to another location.

There is no one right or wrong answer for every installation or application so designers will need to evaluate the required performance on a “project-by-project” basis to decide which technology is optimal.

For today’s large and complex buildings where large numbers of people are confined, restricted, incapacitated or with long egress periods there is one complete solution. It is one which has been used for over 80 years with 100% reliability and is still in use today.

MICC cable being a copper sheathed cable with inert magnesium oxide insulation and copper conductors is in fact 100% flame retardant. It has no fuel element to fuel a fire so it simply cannot propagate fire. As it is metallic with mineral inorganic insulation it is not only Halogen free but free of any and all toxic gasses when burned, including CO and CO2.

No other cable design today can guarantee this performance, or provide the same level of overall fire safety and integrity security throughout the life of the building. MICC cables are also water and oil proof, have a greater current ratings and have smaller diameters compared to other cable deigns. They require no conduit for mechanical, vermin or insect protection, need fewer fittings, are 100% UV, ozone and sunlight resistant as well as radiation resistant, are non-ageing and will operate in cryogenic environments. They are also mechanically stronger than any other cable design in all operating and emergency conditions.

MICC Ltd manufactures Mineral Insulated Cables with copper or special metal alloys capable of meeting all known Fire propagation, Flame and Oven tests. The company provides a guaranteed Fire Proof wiring system which not only is 100% flame retardant but 100% Halogen free, 100% smoke free, 100% toxic emission free with zero organic content. Because MICC has no fuel element it contributes no heat of combustion, creates no oxygen depletion and no contribution to temperature rise.

--------------------------- **MICC cables are for life** -------------------------------

Electric cables:

The primary importance of fire load

When choosing electrical cables for a project or application the choice made is often simple: For non-essential wiring we choose PVC/PVC or XLPE/PVC sometimes with additional mechanical or rodent protection like Steel Wire Armor or in metal conduit. These common, cheap and available cables, when made according to relevant standards and quality systems provide adequate electrical and mechanical properties and are generally easily installed.

In some applications where public safety is important we require electric cables to have added safety features such as flame retardance to ensure the cables do not easily spread fire and circuit integrity during fire so that essential fire-fighting and life safety equipment keep working. Sometimes we may recognize that the combustion of electric cables produces smoke and this can be toxic so we call for cables to be Low Smoke and Halogen Free.

Logically and intuitively we think that by requesting these special properties the cable we buy and install will be safer, especially when we insist that the cables used should conform to some common international standards addressing these properties like IEC, BS VDE or AS/NZS. As with many things in life a little knowledge can be a dangerous thing so in this article I like to dig deeper into the subject of smoke generation, toxicity, halogens and fire safety especially as they relate to electric cables.

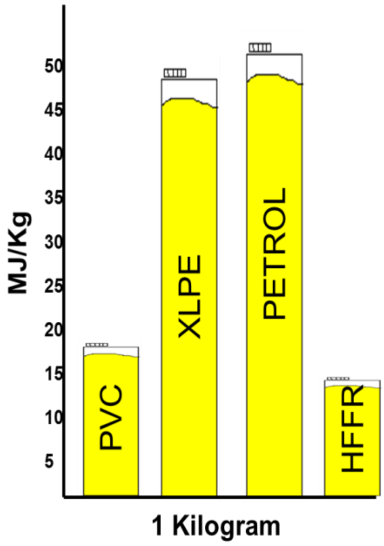
Inside all buildings and projects electric cables provide the connectivity which keeps lights on, air-conditioning working and the lifts running. It powers our computers and office equipment and provides the connection for our telephone and computer systems to communicate with the outside world. Even our mobile phones need to connect with a wireless or GSM antenna which is also connected to the telecom network by fiber optic or copper cables. In addition, cables ensure our safety by connecting fire alarms, emergency voice communication, CCTV, smoke shutters, air pressurization fans, emergency lighting, fire sprinkler pumps, smoke and heat detectors, fire door closers and so many other features of a modern Building Management System.

Whilst we know all of the above, we seldom think much about it because electric cables are mostly hidden and embedded in our constructions. Because cables are installed by many different trades for different applications, what is not often realized is that the many miles of cables and many tons of plastic polymers which make up the cable insulation and jacketing represent one of the biggest fire loads (fuel source) in the building. This point is certainly worth thinking more about.

PVC (polyvinyl chloride), XLPE (cross-linked polyethylene), EPR (ethylene propylene rubber), CSP (chlorosulphonated polyethylene) and even HFFR (Halogen Free Flame Retardant) cable materials are all based on hydrocarbon polymers. These base materials are not flame retardant and naturally have a high fire load. Cable manufacturers make them flame retardant by adding compounds and chemicals. Certainly this can improve the volatility of burning but the fuel content of the base polymers fillers and additives remains.

The following table compares the fire load in MJ/Kg for common cable insulating materials against some common fuels: Petrol / Gas, Coal and Wood. The Heat Release Rate and volatility in air for these materials will differ but the fuel added to a fire per kg and the consequential volume of heat generated and oxygen consumed is relative.

common name	description	MJ/Kg
Petrol		48
XLPE	**Polyethylene**	**46**
PP	**Polypropylene**	**46**
Nylon 66	**Polyamide**	**33**
EPR	**Ethylene propylene rubber**	**28.5**
CSP	**Chlorosulphonated polyethylene**	**28**
Coal		25
PCP	**Polychloroprene rubber**	**24**
Wood		18.5
PVC	**Polyvinyl chloride**	**18**
SIR	**Silicone Rubber**	**15.5**
ETFE	**Ethylene tetrafluoroethylene**	**13.8**
HFFR	**Halogen Free Flame Retardant**	**13**
PTFE	**Polytetrafluoroethylene**	**5**
MICC	**Bare Mineral Insulated Metal Sheathed**	**0**



When we consider the volume in kilometers and tons of cable insulations which we install in our buildings and projects, the fire load of electric cables becomes very considerable. This is particularly important in projects with long egress times such as high rise, in tunnels or underground environments, in public buildings, theaters, airports, hospitals etc..

In considering fire safety we must first understand what are the real and most important dangers. When we talk to the fire experts they tell us most fire deaths in buildings are caused by smoke inhalation, temperature rise and oxygen depletion or by the trauma caused by jumping or falling in trying to escape these effects. So let's take a closer look at each of these:

SMOKE:

The first and most important aspect of smoke is how much smoke? Typically the larger the fire the more smoke is generated so anything we can do to reduce the spread of fire will also correspondingly reduce the amount of smoke.

Smoke from building fires will contain particulates of carbon (soot) ash as well as other solids, liquids and gasses, many are toxic and combustible. In particular fires in buildings, tunnels and in underground or confined areas cause oxygen levels to drop, this contributes to incomplete burning and smoldering which is known to produce significantly increased amounts of smoke along with large volumes of toxic byproducts including carbon dioxide and carbon monoxide. Presence of halogenated materials will also produce toxic Halides like Hydrogen Chloride which combine with the many other toxic and flammable substances and gasses in the smoke.

It is for this reason common smoke tests conducted on cable insulation materials in large 3 meter^3 chambers with plenty of air can provide very misleading smoke generation figures because the complete burning will usually release significantly less smoke than the urning or smoldering which is likely to be experienced in practice. Simply specifying IEC 61034 bscuration value then thinking this will provide a low smoke environment during a real building or underground fire may provide the specifying engineer or authority with a comfort factor but may be little help for the people involved in the fire.

Halogens, Toxicity, Fuel Element, Oxygen depletion and Temperature Rise

It is genuinely concerning that the electrical cable industry in Europe and in many other countries around the world have adopted the concept of halogen free materials without properly addressing the subject of toxicity. Halogens when released during combustion as halides are extremely toxic but so too is carbon monoxide and this is not a halogen gas. It is very common for engineers and authorities to call for halogen free cable insulations and then use Polyethylene because it is halogen free. Burning a Polyethylene cable (which can be seen from the table above has the highest fuel content per Kg of all insulations), generates almost 3 times more heat than an equivalent halogenated PVC cable. What this means is that on burning polyethylene it not only generates 3 times more heat but also consumes 3 times more oxygen and produces significantly more carbon monoxide than burning an equivalent PVC cable. Given carbon monoxide is responsible for most toxicity deaths in fires this situation is at best alarming!

You might then ask if using halogen free materials is a safer option? In America it is not so common for halogen free cables to be specified. The reason is not because Americans are not fully aware of toxicity dangers, they simply have the opinion that by using highly flame retardant materials (even if they contain halogens), the likelihood of a fire spreading is less and therefore any fire is likely to be smaller. A small fire with halogens may be better than a large fire without. The authors opinion is that it is better to use halogen free materials but certainly not if simply replaced by more flammable and high fuel content materials which are arguably much worse and on more levels.

The fuel elements shown in the table above indicates the amount of heat which will be generated by burning 1kg of the common cable insulations tabled. Certainly this heat will accelerate the burning of other adjacent materials and help spread the fire in a building but importantly, in order to generate the heat energy, oxygen needs to be consumed. The higher the heat of combustion the more oxygen is needed, so by choosing insulations with high fuel elements is adding significantly to at least three of the primary dangers of fires: Temperature rise, Oxygen depletion, and Flame spread.

Perhaps the best we can do is install polymeric cables inside metal conduits. This will certainly help flame spread and minimize smoke because inside the conduit oxygen is limited; however this is not a solution. Many of the gasses from the decomposing polymeric insulations inside the conduits are highly flammable. These gases can migrate along the conduits to junction boxes, switch panels, distribution boards, motor control centers, lamps, switches, fire alarm panels and the like. On entering these, the gases can be ignited by any arcing such as the make/break of a circuit breaker, contactor, switch or relay. The gasses can ignite or even explode causing the fire to spread to another location.

Conclusion

If we have learnt anything over the years it is that fires in buildings, tunnels or underground maybe inevitable and that smoke, heat, toxic by-products of combustion and flame spread may be unavoidable. The popularity of "Halogen Free" while ignoring the other toxic elements of fire is a clear admission we do not understand the subject well nor can we define the dangers of combined toxic elements or human physiological response to them.

It is, however important that we do not continue to design with only half an understanding of the problem. While no perfect solution exists for organic based cables, we can certainly minimize these critically important effects of fire:

One option maybe to choose cable insulations and jacket materials which are halogen free and have a low fuel element, then install them in steel conduit. Maybe the American approach is better: to use highly halogenated insulations so that in case of fire any flame spread is minimized.

For most power, control, communication and data circuits we do have one complete solution available. It is a solution which has been used for over 80 years reliably and without fail. MICC cables provide a total & complete answer to all the problems associated with the fire safety of organic polymer cables.

With a copper jacket, magnesium oxide insulation and copper conductors MICC cables are effectively fire proof. Neither the copper jacket or Magnesium oxide or copper conductors have any organic content so simply cannot generate any halogen or toxic gasses at all. They cannot propagate flame and cannot generate any smoke. They have a zero fuel element so cannot contribute any heat to a fire nor can they consume any oxygen in fire.

No other cable design today can guarantee the overall electrical, mechanical and environmental performance of MICC or provide the same level of overall fire safety, integrity and security throughout the whole design life of the project. MICC cables are both water and oil proof, have a greater current ratings with smaller diameters and need fewer fittings compared to other cable deigns. They are radiation resistant, do not permit toxic radiation or biohazard propagation along the cable cores and are ideal for use in nuclear, bio-hazard, chem-hazard and cryogenic environments.

MICC cables are mechanically stronger than any other cable design in all operating and emergency conditions. They do not soften when exposed to high temperatures, are crush, impact and cut through resistant They require no conduit for mechanical protection and termites or rodents cannot eat through the outer sheath of bare MICC cables as they do for served Steel Wire Armored cables.

MICC cables are often used in critical and essential applications, for high rise, public buildings, hospitals with long egress times, for tunnels, metros and underground shopping centers, airports, government buildings, embassies. They are perfect where high or continuous current loading is required and approved for use in all Hazardous locations. The cables are often used for projects with long design lives of 50 years or more and are used frequently in many historic buildings as they are non-aging hence never need replacing and are architecturally compatible in visible locations.

So why is it that MICC cables are not used as often today as they were in the past? The reason is that 30 years ago when flame retardant, halogen free polymeric cables came to the market the cable standards at that time never considered a holistic approach to fire safety. In fact even today they still don't.

Often with contribution from the polymeric cable manufacturers themselves, individual test methods have been created for cable tests to be conducted under carefully prescribed conditions for smoke, flame propagation, circuit integrity, halogen and corrosive emissions and more recently toxicity, often with a mind to repeatability rather than fire reality. These test methodologies have been subsequently and individually adopted by application standards accepted by various authorities and embedded in building regulations.

Unfortunately many of these test methods and the application standards adopting them today mislead users and authorities into believing the cable products they subsequently specify, buy and install will perform as expected in a real fire. As outlined in this paper, sadly this may not be correct.

Today it is better understood that electrical cable insulations represent a very considerable fire load in buildings. It is realized that adopting and specifying simple laboratory tests conducted on cables under specific conditions, which themselves often bear little relevance to real fire environments and with little or no context qualification provided in the standards, may not provide the real fire performance that the test method suggests unless under exposed exactly the same conditions.

Specifically it might be better if:

Flame retardance:	Tests should be conducted on cables preconditioned to operating temperature. Tests for flame propagation under sever current overload should be developed.
Smoke Obscuration:	Tests should be conducted on insulations and jackets at high temperature without flame, when smoldering and when enveloped by flame.
Halogen & Acid gas:	Tests standards must qualify they are not tests determining toxicity and do not test for CO, CO_2 HCN or any other toxic by-product of combustion.
Fire circuit integrity:	Tests should be conducted according to the protocol of the international fire time temperature standard: ISO834-1
Current Ratings:	Standards should clearly identify the life expectancy of cables when operated at the conductor temperatures indicated and give de-rating information for continuous loading.

It would not be fair to blame installing contractors for buying and installing polymeric cables where fire safety is paramount because they are driven by specification, regulation and competitive economics. It is fair to say that standards organizations and regulatory authorities should re-evaluate many of the current test methodologies for fire performance testing of electric cables with a view to holistic and overall fire safety. Specifically the test standards must qualify the methodology used and results obtained with a clear explanation or disclaimer stating that:

"The test method described may not represent actual performance in any given fire event and that the users of the standard should make their own assessments of suitability and relevance of the standard for the intended application".

It is important for consulting and specifying engineers to understand the real performance provided by different cable technologies in order to provide their clients with a system design which has the best possible chance of delivering the overall performance required.

MICC Ltd manufactures Mineral Insulated cables and cable systems with copper or special metal alloys capable of surpassing all known Fire propagation, Flame and Oven circuit integrity tests. The company provides a guaranteed fire proof and inherently fire safe wiring system.

--------------------------- MICC cables are for life -------------------------------

Electrical cables - Life Span

(It's not what you might think)

Almost everything, be it mobile phones, cars, trains, airplanes, buildings, tunnels, bridges have a design life. I have often been dismayed by the apparent design life of my mobile phone but I am never more amazed when I drive over Sydney Harbor Bridge, now over 80 years old, or fly in a 30 year old commercial airplane. How long something is required to provide effective and reliable service in its anticipated environment is a key design criterion which will dictate the choice of design and materials used.

Electric cables are no different and have a useful design life span under specific conditions but unlike many other components, electric cables remain the fundamental arteries or nerve connections that enable every other active component to work. Because electric cables are 'embedded' often it is difficult and expensive to replace them, as such electric cables should ideally provide a reliable service life equal to or better than the equipment connected and often aligned with the project or equipment design life.

Many people think of electric cables as passive electrical components but nothing is further from the truth. On activation, electric cables need to transmit voltage and current over a range of frequencies. Due to the fundamental limitations of conductors and insulations, secondary effects such as resistance, reactance, impedance, capacitance etc. all create unwanted conflicts which need to be both understood and designed out or at least minimized as far as practicable. Connected equipment can also induce unfavorable influences in electrical cables but one very important conflict be it inherent or induced is the effect of conductor resistance on current flow because this creates heat.

Heat in the presence of air is a primary enemy of all polymer insulations but light, some acids, alkalines, salts and gases like Ozone will accelerate degradation. Heat or Thermal degradation is a molecular deterioration caused by the long chain molecules breaking (scission) and reacting with one another to change the properties. These changes typically include reduced flexibility, embrittlement (cracking) chalking, color changes and reduced elongation. In addition to the physical changes of aging performance, operational properties may also be affected and these might include insulation resistance, flame retardance, oil / water resistance etc..

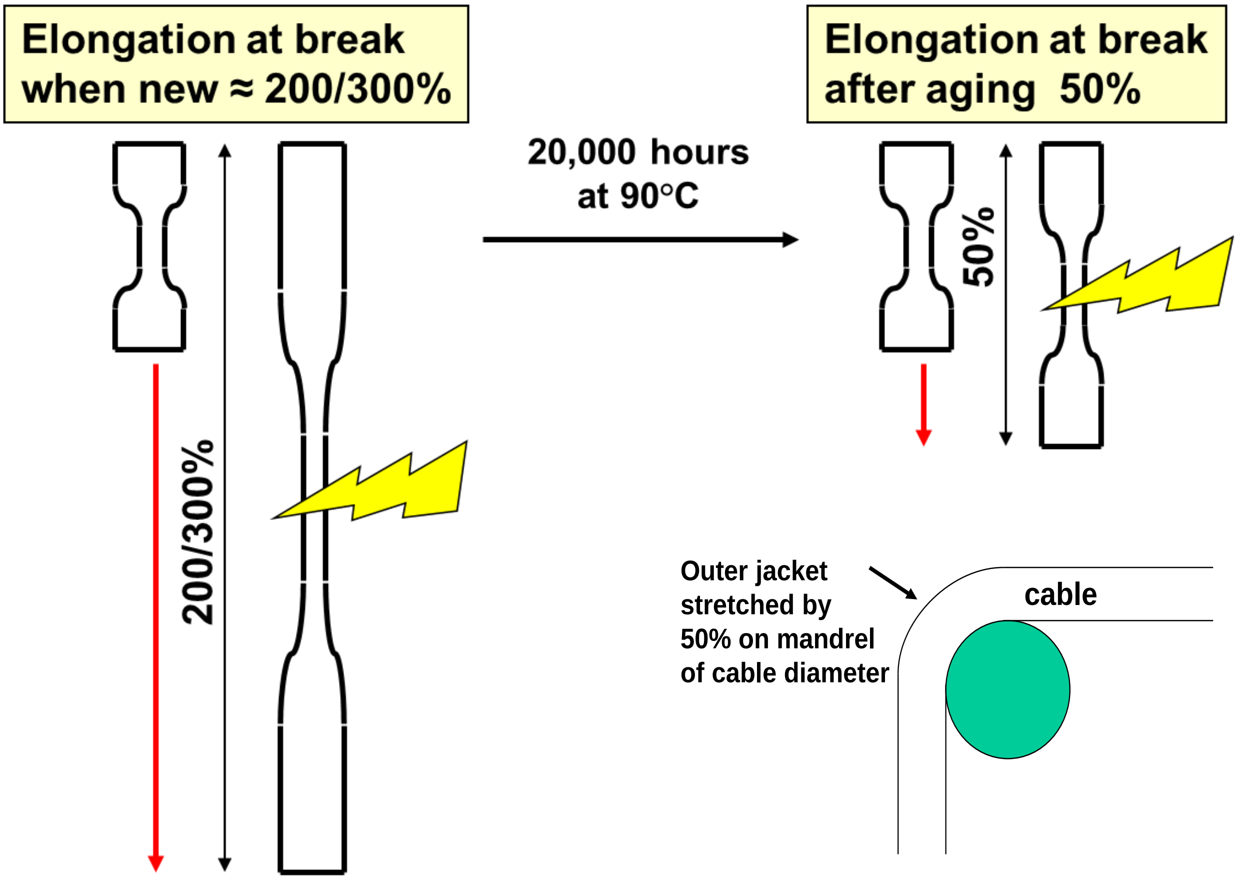
Stabilizers as used in many cable insulations are designed to slow the process by 'mopping up' free radicals but the internationally accepted test method to determine aging performance for electrical insulations is defined by IEC60216 which employs accelerated heat aging of test samples, comparing the aged elongation at break performance against un-aged samples, tabulating the results on an Arrhenius plot and extrapolating to predict extended life performance.

This standard is adopted widely around the world and specifies the calculation and test procedures to be used for deriving thermal endurance characteristics from experimental data obtained in accordance with the instructions of IEC 60216-1 and IEC 60216-2, using fixed ageing temperatures and variable ageing times.

In essence: The temperature rating given to an insulation material is: "That temperature which degrades / reduces the material's elongation at break (EB) to 50% absolute in a period of 20,000 hours exposure" (20,000 hours = 2.3 years).

Common cable insulating materials operating temperature defined by IEC60216 test method:

- PVC = 70°C
- XLPE = 90°C
- EPR / CPE / CSP rubber = 90°C
- Silicon Rubber = 180°C
- Teflon PTFE = 260°C



Cable insulation degradation caused by thermal aging

Understanding why PVC is rated at 70°C and why XLPE is rated at 90°C we can now better understand why the current rating standards we use calculate current ratings for PVC based on a 70°C conductor temperature and for XLPE/EPR based on a 90°C conductor temperature:

- **UK IEE wiring regulations 17th Edition,**
- **IEC 60364-5-52**
- **AS/NZS3008-1**

Perhaps what is not highlighted by these standards is that the elongation reduction to 50% absolute is calculated on 20,000 hours exposure time at this temperature - which is only 2.3 years. In fact these standards do not really expect engineers to use the cables at (PVC) 70°C or (XLPE) 90°C continuously or the cable lifespan will be exceptionally short. They assume usage will be on a basis of discontinuous loading where it is not anticipated the cables will be fully loaded 100% of the time. This pragmatic approach is the only way polymeric cable insulations can be economically viable.

A common 'rule of thumb' for cable polymer insulation aging is that a reduction of 10°C in the average cable operating temperature across its life span will double the insulation life time to the 50%EB (Elongation at Break) point: i.e:

PVC operated continuously at 70°C will degrade to 50%EB in 20,000 hours (2.3 yrs)
operated continuously at 60°C will degrade to 50%EB in 40,000 hours (4.6 yrs)
operated continuously at 50°C will degrade to 50%EB in 80,000 hours (9.2 yrs)
operated continuously at 40°C will degrade to 50%EB in 160,000 hours (18.4 yrs)

XLPE operated continuously at 90°C will degrade to 50%EB in 20,000 hours (2.3 yrs)
EPR operated continuously at 80°C will degrade to 50%EB in 40,000 hours (4.6 yrs)
operated continuously at 70°C will degrade to 50%EB in 80,000 hours (9.2 yrs)
operated continuously at 60°C will degrade to 50%EB in 160,000 hours (18.4 yrs)

Conversely increasing the continuous exposure temperature by 10°C will half the time to 50%EB.

In reviewing the above it must be remembered that any additional chemical, ozone, light radiation exposure, overload or short circuit events will serve to shorten the anticipated cable lifespan.

It is not commonly realized just how quickly common polymeric cable insulations will degrade with time and temperature when operated continuously in air at their rated temperatures:

Insulation Material	*Temperature Rating*	*Continuous exposure for 20,000 hours (2.3 yrs) at rated temp.*	*Expected reduction in elongation at break*
PVC	70°C	70°C	80%
PE and XLPE	90°C	90°C	85%
EPR, CSP,	90°C	90°C	85%

In practice, the use of IEC60216 for determining polymeric insulation temperature ratings by heat aging and elongation at break measurements with the subsequent calculations for determining cable current ratings is pragmatic but only because circuits are not often sized exactly to current demand. Full load current loading of cables circuits can be infrequent and the “averaged’ operating temperature of cables over their lifetime may well be rather less than the maximum conductor temperature ratings quoted in the standards thus extending the cable life span to a reasonable time.

In defense of the mentioned standard: neric cable current ratings based on any more conservative usage would require signi uctor sizes having significant economic impact. Environmental issues might also need to be considered, (although for power circuits corresponding reduction in Watt losses might well compensate for the additional cost over the cable installation life time).

It is critical that electrical design engineers understand the ageing characteristics of polymeric insulations when selecting cables for use in applications where long life is needed and/or where high continuous or for near continuous loading, especially in high ambient temperatures, in sunlight or where higher than normal levels of ozone is expected. Examples may include: Conventional or Nuclear Power Stations, generators, high temperature industrial facilities, transformers, continuous ventilation fans, continuous pumps etc.. In these cases “continuous use” de-rating factors should be applied or the use of cables with a correspondingly higher continuous temperature rating.

There is one cable technology that has been available and widely used for over 80 years and which is simply not affected by aging. MICC cable with its copper outer jacket, inorganic magnesium oxide insulation and copper conductors does not age regardless of heat. It will withstand repeated overload and short circuit events without any degradation. It is unaffected by sunlight, UV, Ozone and resists many chemicals.

For this reason MICC cables are often used in critical applications, for high or continuous loading and for essential safety circuits. MICC cables are often used for projects with long design lives of 50 years or more and are used frequently in many historic buildings as they are non-aging, never need replacing and are architecturally compatible in visible locations. The cable is also approved for use in all Hazardous locations.

Being inorganic MICC cables are totally flame retardant because they have no fuel element to propagate a fire so simply cannot spread flame. For the same reason MICC cannot generate halogen, corrosive or any other toxic gasses when subjected to high heating or fire, including CO and CO2.

MICC cables are also mechanically stronger than any other cable design and in all operating or emergency conditions. They do not soften when exposed to high temperatures, are crush, impact and cut through resistant They require no conduit for mechanical protection and termites or rodents cannot eat through the outer sheath of bare MICC cables as they do for served Steel Wire Armored cables.

No other cable design today can guarantee the electrical, mechanical and environmental performance of MICC cable or provide the same level of overall fire safety, integrity and security throughout the full design life of the project. MICC cables are both water and oil proof, have greater current ratings with smaller diameters and need fewer fittings compared to other cable deigns. They are radiation resistant, do not permit radiation or biohazard propagation along the cable cores and are ideal for use in nuclear, bio-hazard, chem-hazard and in cryogenic environments.

MICC Ltd manufactures Mineral Insulated Cables with copper or special metal alloys capable of meeting all known Fire propagation, Flame and Oven tests. The company provides a guaranteed Fire Proof wiring system which is not only 100% flame retardant but 100% Halogen free, 100% smoke free, 100% toxic emission free with zero organic content. Because MICC has no fuel element it contributes no heat of combustion, causes no oxygen depletion and no contribution to temperature rise. They are also non-aging.

--------------------------- **MICC cables are for life** -------------------------------

Are Electric Cables my biggest ‘Fire Risk’ ?

May 2014

Electric cables provide the connectivity which keeps the lights on, air-conditioning working and the lifts running. It powers our computers, office equipment and provides the LAN connection for computer networks, entertainment systems, telephones, building management, PA and communication systems. Even mobile phones need to connect via a wireless GSM antenna or leaky co-axial cables which are in turn are connected to the telecom network by fiber optic or insulated copper cables. In addition, electric cables enable all the life safety, firefighting and security systems by connecting fire alarms, emergency voice communication and CCTV. They connect smoke extracting fans and shutters, air pressurization fans and dampers, emergency and exit lighting, fire sprinkler pumps, smoke and heat detectors, fire door closers and so many other features of a modern Building Management System. If the essential cable system fails during emergency then the connected emergency equipment fails and likely with devastating consequences.

Whilst we may understand this, we seldom think much about cables because the electric wiring systems we use are mostly hidden and embedded in the construction, ceiling spaces, riser shafts or wall cavities. Because cables are installed by many different trades for different applications, often in polymeric conduit and ducting systems, what is not often realized is that the many miles of cables and many tons of plastic polymers which make up the cable installation system can represent one of the biggest fixed fire loads (fuel source) in the building. This point is certainly worth thinking more about.

Fire Spread & Flame Retardance

Electrical cables are frequently blamed by the media and fire authorities as the cause of fires, however it is often not the failure of the cable which starts a fire but the misuse of the cable by frayed or damaged insulation, overloading due to incorrect or insufficient circuit protection, short circuit or over voltage. These situations can cause high temperatures in the cable conductors or electrical arcing which may heat the cable insulation and any surrounding combustible materials to start a fire.

Most common flexible cables are made from hydrocarbon based polymers. These base polymers are not usually flame retardant and have a high calorific value so cable manufacturers add chemicals to make them more suited to electrical cable use. Halogens like Chlorine are particularly good additives which help retard flame propagation and don't significantly impact the dielectric properties of the polymer, so Halogens are used in both cable insulations and in cable sheaths. These halogenated polymers (example: PVC) also have a negative side-effect because in fire they will release the halogens as halides which are extremely toxic and when combined with moisture in eyes, nose, mouth and lungs are very irritant. Often standard PVC cables may also release large amounts of acrid smoke.

Sometimes, designers realize the dangers of fire spread, halogens & toxic gasses, plus the smoke releasing from cables in fire so they specify cables to have 'Halogen Free' and 'Flame Retardant' properties. In these cases cable manufacturers need to use other non-halogenated materials, mostly with flame retarding fillers like alumina-trihydrate (ATH). While effective in retarding flame propagation, these fillers often negatively affect the polymer by reducing dielectric performance or affecting mechanical & water resistance. For this reason additives like ATH are mostly used only in cable jackets. Halogen Free Flame Retardant cables often use a more pure polymer like Polyethylene (PE or XLPE) or EPR for the insulation which has good electric and mechanical properties but may not be very flame retardant.

Fire Propagation performance

Often the best flame retardant cables are halogenated because both the insulation and outer Jacket are flame retardant but when we need Halogen Free cables we find it is often only the outer jacket which is flame retardant and the inner insulation is not. This has significance because while cables with a flame retardant outer jacket may pass flame retardance tests with an external flame, the same cables when subjected to high overload or prolonged short circuits have proved in university tests to be highly flammable and can even start a fire. This effect is known and published (8th International Conference on Insulated Power Cables in Versailles, France: **http://www.jicable.org/TOUT_JICABLE_FIRST_PAGE/2011/2011-B3-5_page1.pdf**). What this means is your flame retardant cables may not be flame retardant at all in severe short circuit or overload conditions!

Singapore MRT 2013 - Newton Underground Station. Cable overloaded and caught

In America many building standards do not require halogen free cables. Certainly this is not because Americans are not wisely informed of the dangers, rather the approach taken is that: "It is better to have highly flame retardant cables which do not propagate fire than minimally flame retardant cables which may spread or contribute to a fire" (a small fire with some halogens may be better than a large fire without halogens).

Europe and many countries around the world have a different approach: Halogen Free and Flame Retardant. Whilst this is an admirable approach, the reality is rather different: In asking for both flame retardant and halogen free properties, cable manufacturers often compromise between high flame retardance with halogens or reduced flame retardance without halogens.

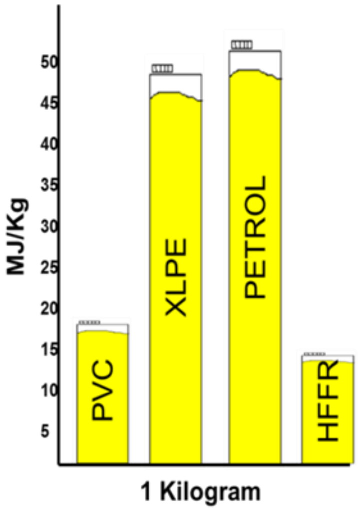
Enclosing cables in steel conduit will reduce flame propagation at the point of fire but hydrocarbon based combustion gasses and smoke from the decomposing polymers will propagate along the inside of conduits to switchboards, distribution boards and junction boxes in other parts of the building where any spark such as the opening or closing of circuit breakers, or contactors is likely to ignite the combustible gasses leading to ignition or even explosion and spreading of the fire and smoke to other locations.

The primary importance of fire load

To provide cables which are halogen free, cable makers most often choose polymers like polyethylene (PE & XLPE) because it is easy to process and cheap however, although polyethylene is halogen free it has a naturally high fire load.

The following table compares the fire load in MJ/Kg for common cable insulating materials against some common fuels. The Heat Release Rate and volatility in air for these materials will differ but the fuel added to a fire per kg and the consequential volume of heat generated and oxygen consumed is relative.

common name	description	MJ/Kg
Petrol		48
XLPE	Polyethylene	46
PP	Polypropylene	46
Nylon 66	Polyamide	33
EPR	Ethylene propylene rubber	28.5
CSP	Chlorosulphonated polyethylene	28
Coal		25
PCP	Polychloroprene rubber	24
Wood		18.5
PVC	Polyvinyl chloride	18
SIR	Silicone Rubber	15.5
ETFE	Ethylene tetrafluoroethylene	13.8
HFFR	Halogen Free Flame Retardant	13
PTFE	Polytetrafluoroethylene	5
MICC	Bare Mineral Insulated Metal Sheathed	0



Pic 1

When considering fire safety we must first understand the most important factors. Fire experts tell us most fire related deaths in buildings are caused by smoke inhalation, temperature rise and oxygen depletion or by trauma caused by jumping in trying to escape these effects. So let's take a look at these factors as they relate to the electrical cable system:

Smoke:

The first and most important aspect of smoke is how much smoke? Typically the larger the fire the more smoke is generated so anything we can do to reduce the spread of fire will also correspondingly reduce the amount of smoke. Highly flame retardant cables with a high oxygen index may help here because they may limit the fire spread.

Smoke will contain particulates of carbon, ash and other solids, liquids and gasses, many are toxic and combustible. In particular, fires in confined areas like buildings, tunnels and underground environments cause oxygen levels to drop near the fire source and this can contribute to incomplete burning and smoldering which may produce increased amounts of smoke and toxic by-products including CO & CO2. As we know presence of halogenated materials will release toxic halides like Hydrogen Chloride together with many other toxic and flammable gasses in the smoke.

For this reason common British and IEC smoke tests conducted by burning cable samples in large 3 meter^3 chambers with plenty of air may provide misleading smoke figures because complete burning in flame can release less smoke than partial incomplete burning or smoldering which is likely in practice (in America NFPA 130 calls for smoke tests in both flaming and non-flaming modes). Simply specifying low smoke cables to common British or IEC standards then thinking this will provide a low smoke environment during a real fire may unfortunately be little of help for the people actually involved.

Halogens, Toxicity, Oxygen depletion and Temperature rise

It is concerning that the UK, Europe and other countries adopt the concept of halogen free materials without properly addressing the subject of toxicity. Halogens released during combustion are extremely toxic but so too is carbon monoxide and this is not a halogen gas. It is common to call for halogen free cables and then allow the use of Polyethylene because it is halogen free. Burning Polyethylene (which can be seen from the table above has the highest MJ fuel load per Kg of all insulations) will generate almost 3 times more heat than an equivalent PVC cable. This means that burning polyethylene will not only generate almost 3 times more heat but also consume almost 3 times more oxygen and produce significantly larger amounts of Carbon Monoxide. Given that it is carbon monoxide which is statistically responsible for most toxicity deaths in fires this situation is at best alarming! (Carbon Monoxide is a colorless and odorless toxic gas which inhibits the blood hemoglobin from absorbing oxygen. Prolonged exposure results in asphyxiation).

The fuel elements shown in the table above (**pic 1**) indicate the amount of heat which will be generated by burning 1kg of the common cable insulations tabled. Certainly this volume of heat will accelerate the burning of other adjacent materials and may help spread the fire in a building but importantly, in order to generate the heat energy, oxygen needs to be consumed. The higher the heat of combustion (MJ/Kg) the more oxygen is needed, so by choosing insulations (even if Halogen Free) with high fuel elements is adding significantly to at least four of the primary dangers of fire: *Temperature rise, Oxygen depletion, Toxic gas emission, and Flame spread.*

Conclusion – Fire Load:

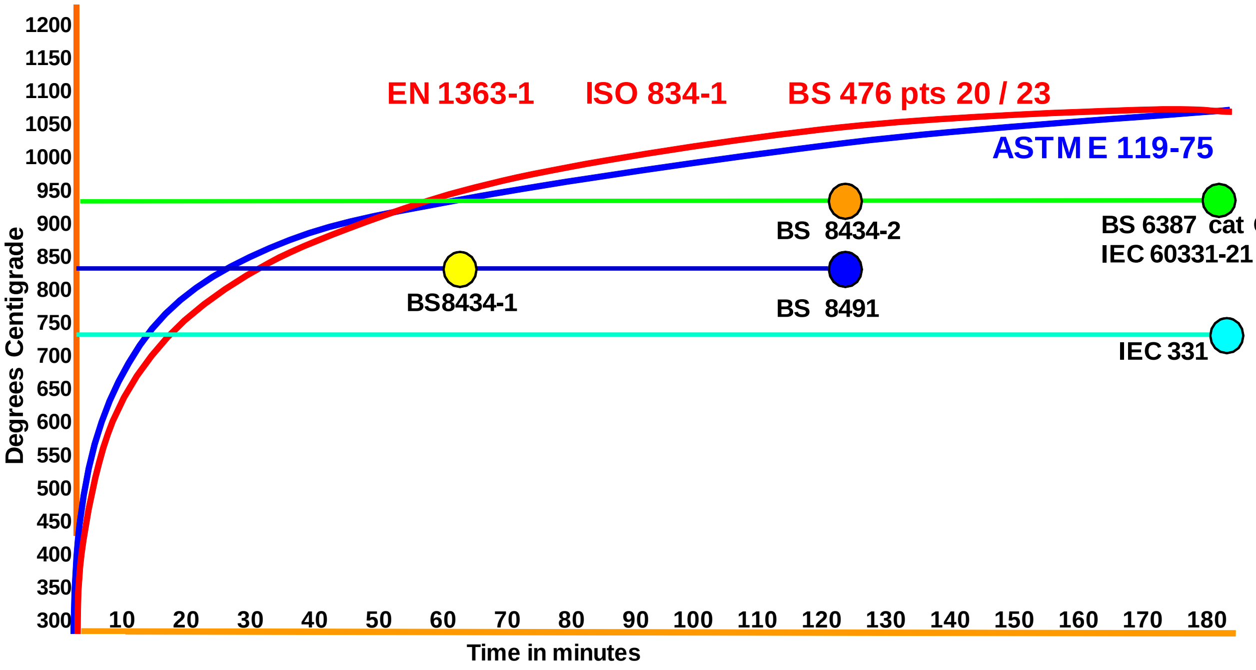
The popularity of "*Halogen Free*" properties while ignoring the other toxic elements of fire is a clear admission we do not understand the subject well nor can we easily define the dangers of combined toxic elements or human physiological response to them. It is important however, that we do not continue to design with only half an understanding of the problem. While no perfect solution exists for organic based electric cables, we can certainly minimize these critically important effects of fire risk:

Essential Life Safety and Fire Fighting circuits

Unlike other cables, fire resistant cables have to work even when directly exposed the fire to keep essential equipment working: Fire alarms, Emergency Lighting, Emergency Voice Communication, Fire Sprinkler pumps, Fireman's Lift sub-main, Smoke extraction fans, Smoke dampers and shutters, Stair pressurization fans, Emergency Generator circuits etc..

It is not commonly understood that fire resistant cables where tested to common British and IEC flame test standards are not required to perform to the same time-temperature profiles as every other structure, system or component in a building. Specifically, where fire resistant structures, systems, partitions, fire doors, fire penetrations fire barriers, floors, walls etc. are required to be fire rated by building regulations, they are tested to the Standard Time Temperature protocol of BS476 parts 20 to 23 (also known as ISO834-1, ASNZS1530pt4, EN1363-1 America & Canada ASTM E119-75). Contrastingly Fire Resistant cable test standards like BS 6387CWZ, SS299, IEC 60331 BS8343-2, BS8491 only require cables to be tested to lower final test temperatures (than BS476 pts 20 to 23). Given Fire Resistant cables are likely to be exposed in the same fire, and needed to ensure all Life Safety and Fire Fighting systems remain operational this fact is surprising.

Contrastingly in Germany, Belgium, Australia, New Zealand, USA and Canada Fire Resistant cable systems are required to be tested to the same fire Time Temperature protocol as all other building elements and this is the Standard Time Temperature protocol or BS476pts 20-23 or ASTM E119-75 in USA.



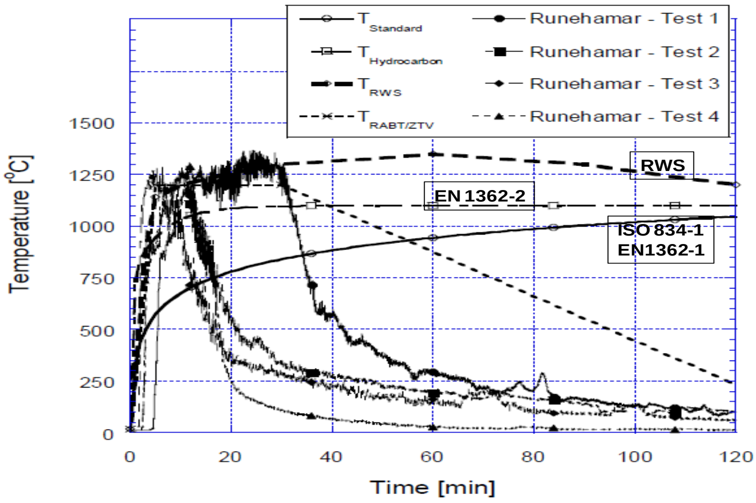
It is also understood today that copper Fire Resistant cables where installed in galvanized steel conduit can fail prematurely during fire emergency because of a reaction between the copper conductors and zinc galvanizing in the metal conduit. In USA and Canada United Laboratories (UL®) in July 2012 removed all certification for Fire Resistive cables where installed in galvanized steel conduit for this reason:

UL® Quote: *"A concern was brought to our attention related to the performance of these products in the presence of zinc. We validated this finding. As a result of this, we changed our Guide Information to indicate that all conduit and conduit fittings that come in contact with fire resistive cables should have an interior coating free of zinc".*

(**http://ul.com/code-authorities/fire-code/fire-resistive-and-circuit-integrity-cables/**)

It is important to understand cable test standards are only 'minimum' requirements and that fires are not all the same. Research by Universities, Institutions and Authorities around the world have identified that Underground environments exhibit very different fire profiles to those in above ground cellulosic environments. Specifically in confined underground public areas like Road and Rail Tunnels, Underground Shopping centers, Car Parks fire temperatures exhibit a very fast rise time and can reach temperatures well above those in above ground buildings. In USA today electrical wiring systems are required by NFPA 502 to withstand fire temperatures up to 1350 Degrees C for 60 minutes and in UK British Standard BS8519:2010 clearly identifies underground public areas and car parks as "Areas of Special Risk". In these environments more stringent test protocols for essential cable circuits may need to be specified by designers.

Time temperature profile of tunnel fires of HGV trailers with different cargo



Haukur Ingason and Anders Lonnermark of the Swedish National Testing and Research Institute presented a paper at the First International Symposium in Prague 2004: Safe and Reliable Tunnels

For Metros Road and Rail Tunnels, Hospitals, Health care facilities, Underground public environments like shopping precincts, Very High Rise, Theaters, Public Halls, Government buildings, Airports etc. this is particularly important. Evacuation of these public environments is often slow even during emergencies, and it is our responsibility to ensure everyone is given the very best chance of safe egress during fire emergencies.

For many power, control, communication and data circuits there is one technology available for all the issues raised in this paper. It is a solution which is frequently used in demanding public buildings and has been employed reliably for over 80 years. MICC cable technology can provide a total & complete answer to all the problems associated with the fire safety dangers of modern flexible organic polymer cables.

The copper jacket, magnesium oxide insulation and copper conductors of MICC cables ensure the cable is effectively fire proof. Bare MICC cables have no organic content so simply cannot propagate flame or generate any smoke. The zero fuel-load of these MICC cables ensures no heat is added to the fire and no oxygen is consumed. Being inorganic these MICC cables cannot generate any halogen or toxic gasses at all including Carbon Monoxide. MICC cable can meet all of the current and building fire resistance performance standards in all countries and are seeing a significant increase in use globally.

Many engineers have previously considered MICC cable technology to be “old school’ but with the new research in fire performance MICC cable system are now proven to have far superior fire performances than any of the newer more modern flexible fire resistant cables.

MICC cable systems are available from **The TRM & MICC Group** www.temperature-house.com.

Wiring Systems for Hospitals and Health Care facilities

June 2014

White Paper

Hospital Fires

The first thing they heard was the fire alarm but no one took much notice. A staff nurse said "Is this a drill or false alarm?" Everyone just carried on doing what they were doing. The Senior staff nurse on the ward called security to ask if this was a drill or a real alarm. They said they didn't know. She waited a minute while the alarm continued and decided to call the ADON.

The ADON, Sharon had also heard the alarm and had been trying to call security and senior management but the phone lines did not work so she was trying to call on her personal mobile phone. She called the COO's personal hand phone who said that she too did not know if it was a real emergency but told Sharon to prepare the wards for evacuation if needed. Sharon hung up and that's when she started to smell the smoke. Sharon immediately tried to call her ward nurse managers but again the fixed phone lines were not working. She started running to the closest ward 8, while running she was trying to call the other ward nurse stations from her mobile phone but could not get through, so she started calling the ward managers on their personal mobile phones.

Sharon managed to contact her Nurse Managers on wards 9 and 11 and asked about the fire, both wards reported increasing smoke so Sharon then ordered an immediate evacuation but she still could not contact wards 7, 12, 6 and 5.

On entering Ward 8 which was closest to her office, she could see the smoke clouding along the corridor ceiling and a nasty acrid smell, she immediately called the evacuation. Nurses had already started escorting the walking patients to the fire stairs, some with drips attached, some in wheelchairs but the non-ambulant patients were still in their rooms. People were shouting and running in all directions.

Sharon shouted to a group of people not to use the lifts and told the attending Nurse to quickly escort the walking patients to the car-park evacuation site via the fire stairs. She then asked one nurse who was escorting a frail patient if the ward medical gases valves had been shut off – the Nurse said did not know but SN Jean might as she was the ward fire warden on this shift. It was then Sharon realized that the ward had 26 patients but only 6 nurses on this weekend shift, this would not be enough.

She shouted at two catering staff to leave the meal trolley and help escort some other walking patients and visitors to the car park evacuation point. She wanted to find the ward Nurse Manager Susan but no one knew where she was. She shouted at one passing Nurse "get the patient records and give them to each patient or their family to take" at the same time. Running down the ward corridor Sharon kept trying to call wards 7, 12, 6 and 5 on her mobile phone but still the lines were busy. She rushed from room to room trying to find out how many patients were still in their beds she found a few with distressed relatives asking what to do.

The smoke in the corridor was starting to get thicker and more stinging, it was unpleasant to breath and Sharon's eyes were running. She felt the first pangs of panic. Sharon ordered the only nursing staff she could see to set-up oxygen cylinders for the non-ambulant patients because the ward oxygen supply was now closed, the nurse said this was already done. Sharon then told her to move all non-ambulant bed ridden patients into one room near the fire stairs, get stretchers ready from the ward store, then close the door and seal the doors with wet towels to stop the smoke entering. The Nurse asked if she should stay with the patients. Sharon said no! Help clear the rest of the ward and assist the walking patients to evacuate.

Sharon then decided she had to make sure the other wards were evacuating. She decided to run up the stairs to ward 12 with a plan to work her way down to each ward. Entering the stairwell she noticed the fresher air but also many people and patients some with drips and drains descending the stairs. In the stairwell there was a patient still in his wheelchair being 'man-handled' down the stairs by two relatives, it was blocking others from evacuating quickly and more able people were trying to push past.

It was hard to climb up the stairs against the slowly descending crowd but she struggled on. Eventually Sharon got to Ward 12 and entered the ward corridor. The smoke was less here than on ward 8 but she knew the stairwell was very crowded. Nurses on ward 12 had already started to tell patients and visitors to leave and they had lined up several beds in the corridors with non-ambulant patients, drips and monitors attached to evacuate.

Sharon shouted to the nursing staff: 'Turn off the ward medical gas!" and she asked where is Nurse Manager Amy? She found Amy in a ward preparing to move a sedated post-operative cancer patient with drains, drips and monitors attached. Sharon asked how many patients were still on ward. Amy said 2 and both non-ambulant. Sharon said you can't use the stairs they are already full and if we put them in wheelchairs or stretchers we will block the stairs even more Amy cried what do we do then?

Get spare oxygen cylinders and lines set for these 2 patients and move them to the room near the fire stairs, tell the nursing aides and other staff, to take all the walking patients down the fire stairs immediately. Amy said shall I tell them to then come back up after to help all the others? Sharon hesitated realizing the likely tragic consequences of her reply, she said no.

National Health Service report:

A report published by (NHS) National Health Service in the UK on 5 major hospital fires in London during the period January 2008 to February 2009 highlights that fires in Hospitals are not as uncommon or unlikely as we might like to think. The NHS report quoted: "*2008/2009 saw a number of significant fires at NHS sites in London which required the evacuation of part or whole of the building. Any evacuation of a large commercial building is difficult – coping with a facility as complex as an NHS site, complete with sick and recovering patients, staff and visitors presents further challenges*".

- **Royal Marsden Hospital** Specialist cancer hospital Wednesday, 2nd January 2008 Complete evacuation
- **University College Hospital London** teaching hospital Friday, 25th July 2008 Part closure and service diversion
- **Great Ormond Street Hospital** Paediatric tertiary referral center Monday, 29th September 2008 Partial evacuation
- **North London Forensic District general hospital** site, shared Wednesday, 15th October 2008 Complete evacuation
- **Northwick Park Hospital** District general hospital Wednesday, 11th February 2009 Partial evacuation

So why is it that hospitals are a higher fire risk than other public buildings ?

Direct quotes from the NHS report include:

"Hospitals are well prepared for major external incidents and events which cause a surge in patient numbers. However circumstances resulting in internal hazards such as fire, escape of gases or dangerous substances, utility failure, serious flooding, and non-structural or structural damage may necessitate the evacuation of a hospital or healthcare facility, either as a whole or part. These events are arguably more disruptive than external incidents, as they put increased stress on hospitals that traditionally operate at full capacity."

"The short and long term consequences from hospital failure not only include loss of life, financial implications and challenges in providing health services, particularly if facilities require rebuilding following the event, but also cause intangible far-reaching effects on the community through loss of their 'safe haven'."

"Fires in hospitals may be particularly worrying, not only from flames and heat generated, but also smoke which can travel long distances inside buildings aided by air conditioning systems. The type of smoke or products of combustion generated will vary from the type of fire (blazing or smouldering) to the sort of material being burnt such as the building, the roofing, or hospital plastics or waste to more specific material such as hospital gases, drugs or even radioactive sources. The need to understand the hazards and risks under these circumstances requires understanding by hospital staff and planners, plus support from experts including those at the Health Protection Agency (HPA)."

A hospital is often full of patients many non-ambulant, unconscious or under the effects of drugs and sedation. There are operating theaters and treatment rooms, Intensive care facilities, MRI, Cat Scan, X-Ray, Nuclear medicine rooms. In Pediatric hospitals there may be new born babies and sick children. There is staff for nursing, catering, cleaning, administration, security, maintenance as well the doctors and specialists. Then there are the many visitors. Unlike in office and residential buildings many people are not familiar with the hospital layout or evacuation plans.

Hospitals have the added complication of piped oxygen and medical gases to each ward, treatment room, operating theater and A&E department, further back up oxygen cylinders are kept in every ward. Adding to the risks are stores of flammable liquids needed for sterilization, sensitive and highly flammable X-RAY films and even radioactive elements.

For all these reasons Hospitals present one of the most challenging environments to design, build and plan for safety and evacuation during fire or emergency events. Generally in many countries, Nursing and permanent hospital staff are well trained on emergency and evacuation procedures but the simple fact is that with rising costs, limited budgets, shortages of nurses and other staff, there may simply not be enough staff to ensure fast and safe evacuation of all the patients and visitors in severe fire events, especially if these occur at night or on weekends.

With this in mind architects, consulting engineers, builders, emergency services, hospital management and staff all need to make special planning for hospital emergencies. This planning often starts with at hospital building concept stage with Architects, Consultants and Hospital Management.

Electric cables provide the connectivity which keeps the lights on, air-conditioning working and the lifts running. It powers the computers and office equipment and provides the connection for computer networks, entertainment systems telephones and PA systems. Patient monitoring and call systems, Nursing management systems etc.. Even mobile phones need to connect with a wireless GSM antenna or leaky co-axial cables which are also connected to the telecom network by fiber optic or insulated copper cables. In addition, cables enable the safety and security systems by connecting fire alarms, emergency voice communication, CCTV. They connect smoke extracting fans and shutters, air pressurization fans, emergency and exit lighting, fire sprinkler pumps, smoke and heat detectors, fire door closers and so many other features of a modern Building Management System. If the essential cable system fails the emergency systems fail and this would have devastating consequences.

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Propagation performance in Fire

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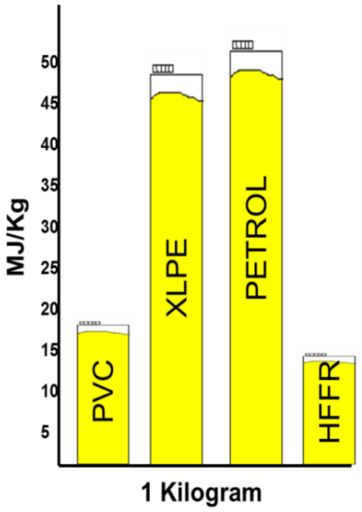
MICC	Bare Mineral Insulated Metal Sheathed	0



When considering fire safety we must first understand the most important factors. Fire experts tell us most fire related deaths in buildings are caused by **smoke inhalation, temperature rise** and **oxygen depletion** or by trauma caused by jumping in trying to escape these effects. So let's take a look at these factors as they relate to the electrical cable system:

Smoke:

The first and most important aspect of smoke is how much smoke? Typically the larger the fire the more smoke is generated so anything we can do to reduce the spread of fire will also correspondingly reduce the amount of smoke. Highly flame retardant cables with a high oxygen index will help here because they may limit the fire spread.

Smoke will contain particulates of carbon, ash and other solids, liquids and gasses, many are toxic and combustible. In particular, fires in confined areas like buildings, tunnels and underground environments cause oxygen levels to drop near the fire source and this contributes to incomplete burning and smoldering which can produce increased amounts of smoke and toxic by-products including CO & CO2. As we know presence of halogenated materials will release toxic halides like Hydrogen Chloride together with many other toxic and flammable gasses in the smoke.

For this reason common BS and IEC smoke tests conducted by burning cable samples in large 3 meter^3 chambers with plenty of air can provide misleading smoke figures because complete burning in flame can release less smoke than partial incomplete burning or smoldering which is likely in practice. In America NFPA 130 calls for smoke tests in both flaming and non-flaming modes. Simply specifying low smoke cables to common British or IEC standards then thinking this will provide a low smoke environment during a real fire may unfortunately be little of help for the people actually involved.

Halogens, Toxicity, Oxygen depletion and **Temperature rise**

It is concerning that the UK, Europe and other countries adopt the concept of halogen free materials without properly addressing the subject of toxicity. Halogens released during combustion are extremely toxic but so too is carbon monoxide and this is not a halogen gas. It is common to call for halogen free cables and then allow the use of Polyethylene because it is halogen free. Burning Polyethylene (which can be seen from the table above has the highest MJ fuel load per Kg of all insulations) will generate almost 3 times more heat than an equivalent PVC cable. This means that burning polyethylene will not only generate almost 3 times more heat but also consume almost 3 times more oxygen and produce significant amounts of carbon monoxide. Given carbon monoxide is responsible for most toxicity deaths in fires this situation is at best alarming!

The fuel elements shown in the table above indicate the amount of heat which will be generated by burning 1kg of the common cable insulations tabled. Certainly this volume of heat will accelerate the burning of other adjacent materials and may help spread the fire in a building but importantly, in order to generate the heat energy, oxygen needs to be consumed. The higher the heat of combustion the more oxygen is needed, so by choosing insulations with high fuel elements is adding significantly to at least four of the primary dangers of fire: **Temperature rise, Oxygen depletion, Toxic gas emission,** and **Flame spread.**

Conclusion – Fire Load:

The popularity of “Halogen Free” properties while ignoring the other toxic elements of fire is a clear admission we do not understand the subject well nor can we easily define the dangers of combined toxic elements or human physiological response to them. It is important however, that we do not continue to design with only half an understanding of the problem. While no perfect solution exists for organic based electric cables, we can certainly minimize these critically important effects of fire risk:

One option maybe to choose cable insulations and jacket materials which are halogen free and have a low fuel element, then install them in steel conduit. Maybe the American approach is better: to use highly halogenated insulations so that in case of fire any flame spread is minimized. Another would be to use MICC cables and eliminate all the above mentioned risks.

Essential Life Safety and Fire Fighting circuits

Unlike other cables, fire resistant cables have to work even when directly exposed the fire to keep essential equipment working: Fire alarms, Emergency Lighting, Emergency Voice Communication, Fire Sprinkler pumps, Fireman's Lift sub-main, Smoke extraction fans, Smoke dampers and shutters, Stair pressurization fans, Emergency Generator mains etc..

It is not commonly understood that in UK many parts of Europe, Singapore, S.E. Asia and many other parts of the world the fire resistant test methods qualifying these cables are very different to the fire test methods required for every other fire rated structure component and system in the building. Specifically the final test temperatures for these cables tests are lower than for the other fire rated parts of the building. What this means is if you have a 2 hour fire rated wall, partition, door, penetration floor etc. this does not mean the essential fire resistant cables have the same fire resistance rating.

Why these cables should be tested and qualified to different tests with lower final temperatures is an interesting and open question.

In America, Canada, Germany, Belgium, Australia and New Zealand essential fire resistant cable systems including supports and fixings are all required to be tested to the same time temperature test protocol as every other fire rated structure, component and system in the building. Intuitively this is logical given these essential cables which are needed to keep all life safety systems working are likely to be exposed to the same fire.

For Hospitals and health care facilities this is particularly important. Evacuation of hospitals is complex, slow and demanding. Patients, Nurses, Healthcare workers, visitors, doctors and support staff all need to be given the very best chance of safe egress during fire emergencies.

For many power, control, communication and data circuits there is one complete and total solution available for all the issues raised in this paper. It is a solution which is frequently used for Hospitals and has been employed reliably for over 80 years. MICC cables provide a total & complete answer to all the problems associated with the fire safety dangers of organic polymer cables.

The copper jacket, magnesium oxide insulation and copper conductors of MICC ensure the cable is effectively fire proof. MICC cables have no organic content so simply cannot propagate flame or generate any smoke. The zero fuel load of MICC cables ensures no heat is added and no oxygen is consumed. Being inorganic MICC cables cannot generate any halogen or toxic gasses at all including Carbon Monoxide.

MICC cables are manufactured and supplied By MICC Ltd. The use of MICC cables for Hospital wiring systems will reduce the overall fixed fire load, reduce flame spread, reduce the amount of smoke, reduce the halogen and Toxic gas problem, reduce the heat generated and reduce oxygen depletion. MICC cables will ensure that the vital Life Safety and Fire Fighting equipment works reliably when and for as long as they are needed.

Wiring Systems for

Road and Rail Tunnels

By Richard Hosier and Geoff Williams

July 2014

Wiring Systems for Road and Rail Tunnels

Road, Rail and long Pedestrian tunnels require a significant amount of power to operate safely. Power is usually supplied from the electricity grid but Tunnels have to operate safely even with blackouts, so emergency back-up power is almost always provided in large Tunnel systems. It is not any single system which is most important in tunnel design, rather it is only when all operational and safety systems are working together which can ensure the integrated, reliable and effective operation of life support in both normal and emergency conditions.

Bryngläs tunnel fire 2011

Emergency events in tunnels can include any occurrence: Terrorist bombs, gas attacks, earthquake, flooding, collapse or accidents but perhaps the most demanding and likely emergency is fire. Fire has the potential to endanger people even away from the fire source, not because of heat but from the secondary effects of smoke and toxic combustion gases. For this reason Tunnels are designed to manage fires to enable the best possible survivability.

Tunnel safety systems include: Alert systems, Surveillance, Traffic control, Automatic Incident detection, Automatic Smoke Fire and Heat detection, Emergency Communication by Fixed, Telephone, GSM, FM and Loud Speaker systems, Lighting for normal and emergency conditions, Ventilation, Fans, Shutters and Dampers for air quality and Smoke management in normal, evacuation and Fire Fighting modes, Fixed Fire Fighting systems, Pumps & Controls, Barrier systems and others.

It is somewhat obvious but often understated that electrical cables provide the connectivity enabling all this equipment to work and that the reliable performance of the wiring system is directly responsible for the reliable performance of all tunnel operating and safety systems. As such, the wiring system must have an operational integrity equal to or even better than the connected equipment. It must operate reliably for the design life of the tunnel without degradation and under both normal and emergency conditions.

So do we have cables ***"Fit for Purpose"?*** The answer is both 'yes' and 'no' That is: **Yes** we do have cable systems but **No** we don't always use them.

In most parts of Europe, Britain and in many countries around the world, the most common wiring systems used in tunnels for essential Life Safety and Fire Fighting systems are made to pass flame tests which are fundamentally inferior to the fire tests we demand for all other fire rated structures, components and systems. Specifically, common BS and IEC flame integrity tests for Fire Resistant cables only require flame withstand performance for 2 hours or less to 842˚C to BS8491:2008 or 930˚C to BS8434-2:2003 & 830˚C to BS EN50200:2006 or 3 hours at 950˚C to IEC 60331 and BS6387:2013 Cat C. All other structures, systems and fire resistant components require fire testing in full scale ovens with temperatures rising well above 1,000˚C. ***So why are fire resistant cables allowed to be tested to different standards and at lower final temperatures?***

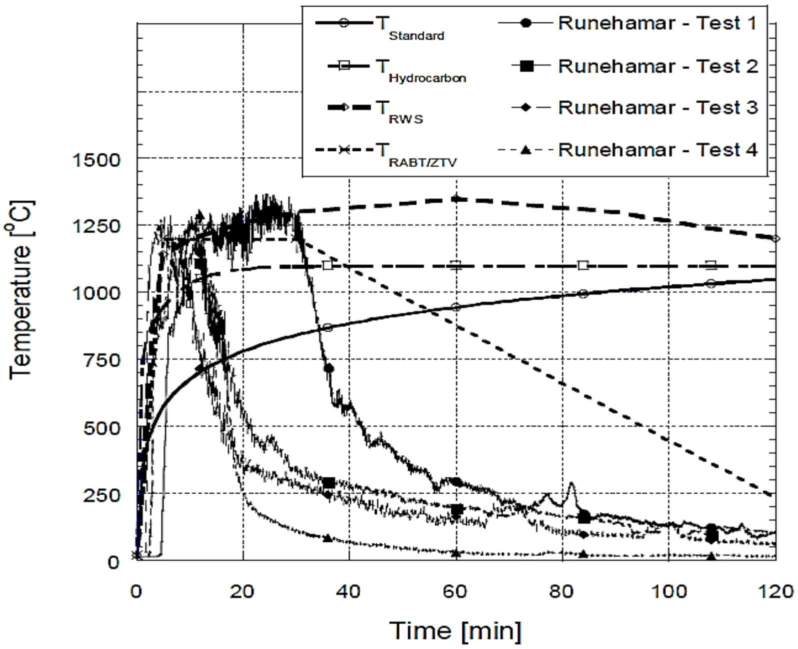
Interestingly this is not the case in Germany, Australia New Zealand, Belgium and USA/Canada where fire resistant wiring systems are required to meet higher time temperature test protocols according to the **Standard Time Temperature Curve: (**EN834-1 / BS476pt 20-23 or ASTM E119 in USA) with fire temperatures rising well over 1,000˚C for periods up to 2 hours. This is the same time temperature protocol as used for all other structural and fire resistant components.

The **Standard Time Temperature Curve** was designed and first published in 1918, generally intended for above ground cellulosic buildings and it still forms the basis for fire resistance testing of building structures, systems and components today. It replicates with reasonable accuracy most common fire scenarios in above ground domestic and commercial building environments, however we know well from significant research that fires in tunnels and underground environments can exhibit far more extreme scenarios.

For enclosed environments such as in road, rail, pedestrian tunnels, underground car parks, underground shopping malls, etc. heat generated by fire is often not able to escape as easily as it might in above ground buildings. Smoke and heat build-up can be more rapid and from experience and testing has shown that the resulting fire temperatures can often reach levels well in excess of those experienced in above ground buildings and in far less time. In these cases even the Standard Fire Time Temperature Curve may not be optimal.

Summit Tunnel – Tordmorde UK 1984

In some Road and Rail Tunnels, fire resistance of structures, equipment and systems are required to survive fire Time Temperature environments well above the Standard Time Temperature Curve. Newer test protocols like the Hydrocarbon curve: EN 1363-2, BS476 appendix D, AS/NZS1530pt 4 appendix D., the German RABT-ZTV (car) or (train) or the French HCM (Modified Hydrocarbon Curve) are sometimes used. Contrastingly in most parts of Europe, Britain and in many other countries, the Fire Resistant cable systems employed in tunnels are still often only required to meet the simple and lower temperature British or IEC flame test standards which arguably fall well short of even the Standard Time Temperature Curve protocol.



Full scale fire tests in Tunnels utilizing road vehicles including passenger cars, busses, trucks with different loads and rail vehicles including Intercity and Metro / Underground carriages, has established that for enclosed tunnel environments fire temperatures exhibit a very fast rise time and can easily reach temperatures well above the parameters of the Standard Time Temperature protocol of ISO 834-1.

Haukur Ingason and Anders Lonnermark of the Swedish National Testing Research Institute presented a paper at the First International Symposium in Prague 2004: Safe & Reliable Tunnels

Such testing has also established that it is unlikely, at any one point in the tunnel that a cable, structure or a component will experience the extremely high peak fire temperature for much longer than 30 to 40 minutes because in this time most of the fuel at that point will have burnt away. Of course fire spread may move the fire front along the tunnel. The learning from this is that wiring systems used in tunnels and underground environments must be able to withstand very high peak fire temperatures but perhaps for rather less time than we test today.

In USA today, NFPA®502 **Standard for Road Tunnels, Bridges, and other Limited Access Highways** requires emergency circuit wiring to meet the higher performance of almost 1,350˚C but only for 1 hour (Netherlands RWS RijksWaterStaat curve).

So why, when all this essential information is known and published do we often use Fire Resistant wiring systems in Tunnels and underground environments which are only tested to lower standards ?

The reason is often that designers rely on the common wiring and electrical standards applicable in each respective country, perhaps not realizing that standards publications are just "minimum" requirements and often only intended for above ground applications. It is left to the designer and Tunnel owner to demand if higher performances are required and sometimes when it comes to electrical wiring systems this is fact is simply overlooked.

Of course some designers route tunnel cables in sand pits or in cable trenches or behind fire resistant tunnel linings. Where this is done the performances may be acceptable due to additional thermal protection but for surface wiring or where cables cannot be protected then appropriate wiring systems must be employed.

As to which wiring system is optimal there are two questions to ask:

1) ***Will the cable survive during fire to keep essential Life Safety and Fire Fighting systems operational*?**
2) ***Do the cables themselves pose a fire risk or add any fire load?***

Most flexible electric cables are made from hydrocarbon based polymers. Cable jackets are sometimes loaded with flame retardant fillers but often cable insulations are not so these cables may not be fully flame retardant in all situations, especially under overload or short circuit. The high Fire Load of cable insulations, especially polyethylene (even though Halogen Free) poses

significant fire risk because PE or XLPE in fire has a very high Heat Release rate, a high oxygen consumption and a high CO and CO_2 outgassing, which contribute to temperature rise, fire spread and asphyxiation risk.

Installing cables in conduit does not solve the problem because decomposition of polymers inside the conduit spreads smoke, toxic and flammable hydrocarbon gasses along the conduits to equipment and distribution boards where any spark such as make or break of circuit breakers, switches or relays can ignite the gasses spreading fire to another location.

One good solution, MICC / MIMS cables uses inorganic magnesium oxide insulation with copper or alloy cable jackets and copper or alloy conductors. These cable designs have no fire load at all so simply cannot propagate fire or add any heat. They produce no smoke, no toxic or flammable gasses at all and can be made to meet any of the higher fire resistance performances for exposed surface wiring. The cable design is in service with London Underground and many other Metro systems worldwide, the cable is 100% water proof, non-aging, with exceptional fire survival performance "*as proven and reported after the Anglo/French Channel Tunnel fire in 1996".*

Regrettably many polymeric based Fire Resistive cables are also still used in tunnels today because common electrical cable standards do not always differentiate between applications thus allowing the use of cheap, lower performance cables which often are not designed for, or even "Fit for Purpose" in the more demanding environments of Tunnels.

Excerpts from the conclusion in the Doctoral Thesis of Anders Lonnermark, Department of Fire Safety Engineering Lund Institute of Technology Lund University 2005:

The rapid increase in temperature and heat release after initial development. means there is only a short period to begin evacuation. Toxicity calculations corroborate this.. It is a question of minutes.

Wiring Systems for the Nuclear & Conventional Power Industry

September 2014

The fact is that almost everything will change over time and that rate of change is often highly dependent on the environment. Organic based electric cable insulations are particularly subject change.

Electric cables with organic polymer insulations have a useful design life span under specific conditions but unlike many other components, electric cables remain the fundamental arteries or nerve connections that enable every other active component to work. Because electric cables are ‘embedded’ often it is difficult and expensive to replace them, as such electric cables should ideally provide a reliable service life equal to or better than the equipment connected and often aligned with the project design life.

The nemesis of most cable polymer aging is heat in the presence of air (more accurately oxygen) but chemicals, gases, water, light, radiation, mechanical (static and dynamic) stressors will all contribute and multiply the speed of aging. These effects can be seen as both physical and electrical changes in the material properties, like reducing flexibility, deterioration of the materials elongation at break, hardening, cracking, surface chalking, discolouration and decreasing dielectric performance.

Electric cables transmit voltage and current over a range of frequencies. Due to the fundamental limitations of conductors and insulations, secondary effects are created like resistance, reactance, impedance, capacitance etc. but one very important conflict is the effect of conductor resistance on current flow because this creates heat.

Heat in the presence of air is a primary enemy of all polymer insulations. Thermal degradation is a molecular deterioration caused by the long chain molecules breaking (scission) and reactions within the polymer which change the properties over time. These changes typically cause reduced flexibility, embrittlement (cracking) chalking, color changes and reduced elongation. Other operational properties may also be affected including insulation resistance, flame retardance, oil / water resistance etc..

This article explores the aging of polymeric cable insulations and questions if the common useful life prediction standard “50% residual Elongation at Break” (EAB) as used today for general domestic, and commercial applications is also appropriate for the Nuclear and Conventional Power Industry, or if more stringent performance criteria should be adopted.

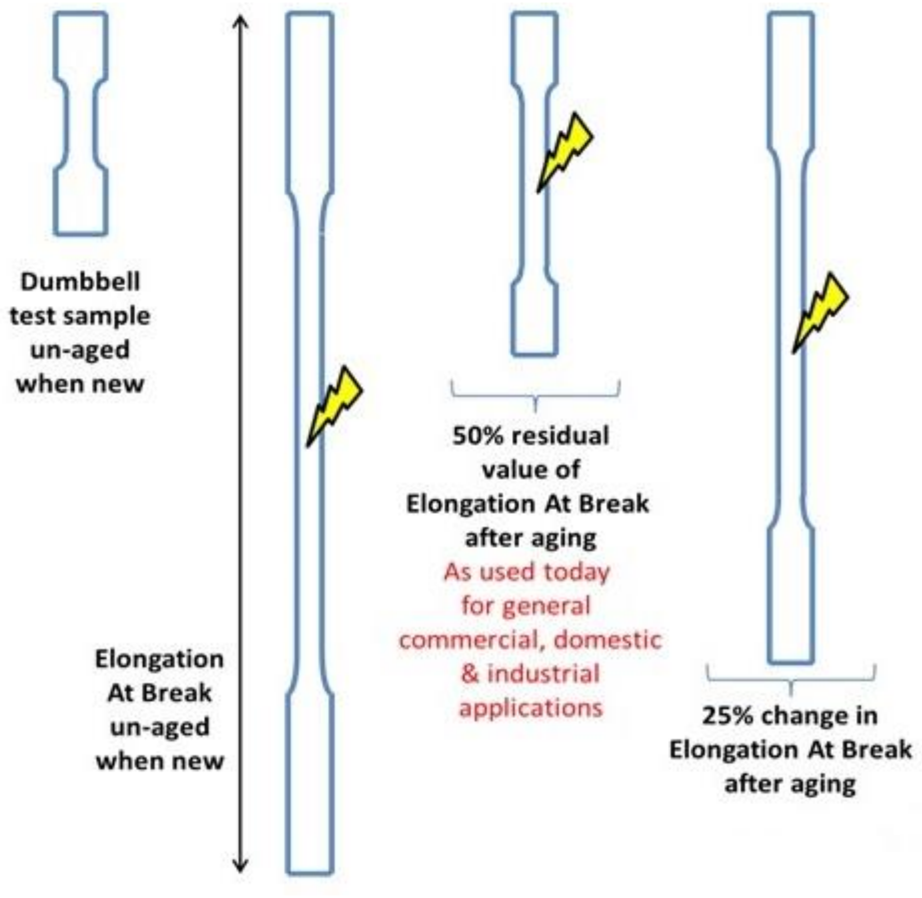
Aging

A standard widely adopted around the world to determine aging performance for polymeric cable insulations is IEC60216 which employs accelerated heat aging of test samples, comparing the aged Elongation At Break (EAB) performance against un-aged samples, tabulating the results on an Arrhenius plot and extrapolating to predict extended life performance.

NASA report CR 1787 (Radiation Effects Design Handbook Sect 3. Electrical Insulating Materials) identifies a damage threshold for insulations and polymers where one original property of the material (tensile strength, elongation etc.) has changed by **25%.** For electrical cables in non-space/aerospace applications, like commercial, domestic or industrial applications, we generally adopt the calculation of predicted lifespan by measuring a reduction in EAB (Elongation At Break) to **50% residual** (IEC60216). EPRI (Technical Report 1008211, “Initial Acceptance Criteria Concepts and Data for Assessing Longevity of Low-Voltage Cable Insulations and Jackets” EPRI 2005) also describes 50% residual EAB as a practical end-of-life threshold for cables that may be subjected to a loss-of-coolant accident (LOCA) exposure.

What is not often realized is that a **50% residual** EAB often corresponds to a change in the material properties from new of **80%** or even more. This is significantly different to a **25%** change in one or more physical property.

Given the critical importance of long term system integrity, reliability and performance needed in the Nuclear Power Industry it is appropriate to question if the “50% residual” threshold as used today for domestic, commercial and industrial applications is also acceptable for critical Nuclear Power Industry, or if adoption of a **“change in any one physical property”** would be a safer ‘end of life’ threshold:



Pic 1 Elongation at Break

Today cable manufacturers blend polymers with fillers like plasticizers to improve flexibility, flame retardants to improve the fire performance, stabilizers & anti-oxidants to extend lifespan, pigments for colour and even calcined clays, zinc oxide, paraffinic waxes and oils. These additives can improve insulation and jacket material performance and slow the aging process but they cannot stop it. Unfortunately all the stressors to aging and polymer degradation are additive, so if we factor the normal combinations of cyclic heating and cooling, the occasional overload or short circuit, presence of ozone (which is often greater in coastal areas) occasional exposure to cleaning agents, oils, water, light and humidity (or even the lack of it), polymer aging can be accelerated both considerably and unexpectedly.

Degradation occurs faster where air/oxygen is present so it is common that cable jackets may age faster than cable insulations. This is fortunate because many of the fillers used to improve physical properties like fire performance cannot so easily be added to insulating compounds as they may reduce the dielectric properties. This means a cable may have a flame retardant jacket but the insulation may not be flame retardant. For the possible impact of this see:

http://www.jicable.org/TOUT_JICABLE_FIRST_PAGE/2011/2011-B3-5_page1.pdf

One main cause of polymer degradation is polymer chain scission. This happens when free radicals within or from outside the cable insulation cause breakages in the polymer backbone chain over time. This natural process is accelerated by heat, moisture, light and mechanical stressors. This results in degradation of mechanical performance and the multiple processes combine to increase the number of carriers in the polymer insulation material, thereby increasing the conduction and will ultimately lead to dielectric breakdown.

Pic 2 Aged cables in power station showing cracking.

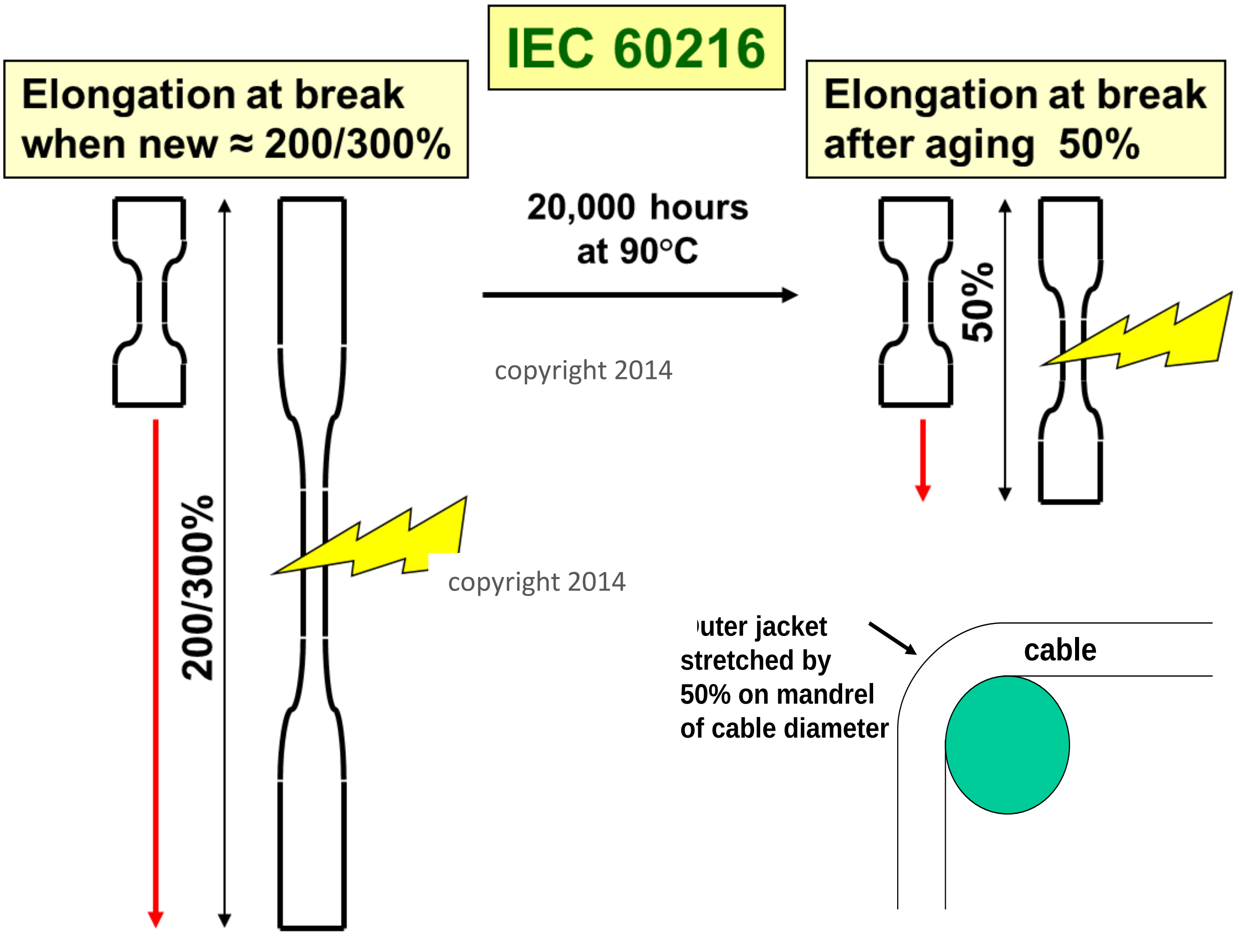
These effects are magnified during exposed to radiation, so despite some LOCA exposure test requirements on Nuclear cables today, if a large or additional radiation exposure was to occur in the presence of old cables the effect may just be enough to push the insulation over the edge to failure, exactly when you might need the cables to operate reliably.

So how long can I expect my cables to last?

IEC 60216 defines that the temperature rating given to an insulation material is: That temperature which degrades / reduces the material’s elongation at break (EB) to 50% absolute (residual) in a period of 20,000 hours exposure (20,000 hours = 2.3 years).

Common cable insulating materials operating temperature defined by IEC 60216:

- PVC = 75°C, XLPE = 90°C, EPR / CSP rubber = 90°C, Silicon Rubber = 180°C, Teflon PTFE = 260°C



Pic 3 Cable insulation degradation caused by thermal aging

Understanding why PVC is rated at 75°C and why XLPE or EPR is normally rated at 90°C we can now better understand why the current rating standards we use calculate current ratings for PVC based on a 75°C conductor temperature and for XLPE or EPR insulations based on a 90°C conductor temperature:

- **UK IEE wiring regulations 17th Edition, IEC 60364-5-52, AS/NZS 3008-1**

Perhaps what is not highlighted by these standards is that the elongation at break reduction to 50% absolute (residual) is calculated on 20,000 hours exposure time at this temperature - which is only 2.3 years. In fact these standards do not really expect engineers to use the cables at (PVC) 75°C or (XLPE) 90°C continuously or the cable lifespan may be exceptionally short. They assume usage will be on a basis of discontinuous loading where it is not anticipated the cables will be fully loaded or heated 100% of the time. This pragmatic approach is the only way polymeric cable insulations can be economically viable.

A common ‘rule of thumb’ for polymer cable insulation aging is that a reduction of 10°C in the average cable operating temperature across its life span will double the insulation life time to the 50% residual EAB (Elongation at Break) point: i.e.:

PVC operated continuously at 75°C will degrade to 50%EAB in 20,000 hours (2.3 yrs)

operated continuously at 65°C will degrade to 50%EAB in 40,000 hours (4.6 yrs)

operated continuously at 55°C will degrade to 50%EAB in 80,000 hours (9.2 yrs)

operated continuously at 45°C will degrade to 50%EAB in 160,000 hours (18.4 yrs)

XLPE operated continuously at 90°C will degrade to 50%EAB in 20,000 hours (2.3 yrs)

EPR operated continuously at 80°C will degrade to 50%EAB in 40,000 hours (4.6 yrs)

operated continuously at 70°C will degrade to 50%EAB in 80,000 hours (9.2 yrs)

operated continuously at 60°C will degrade to 50%EAB in 160,000 hours (18.4 yrs)

Conversely increasing the continuous exposure temperature by 10°C can half the time to 50% residual EAB. In reviewing the above it must be remembered that any additional chemical, ozone, light radiation exposure, overload or short circuit events can serve to shorten the anticipated cable lifespan.

Of course where polymers have been formulated to have this degradation to EAB to 50% residual at higher temperatures or is slowed by additives and special formulations, then the predicted lifespan at an anticipated mean temperature might be longer. Example: Where a polymeric insulation qualifies for a 110°C temperature rating but is operated at a mean temperature of only 60°C (as per examples above) the 50% EAB will extrapolate out to 73.6 years (perhaps aligning with a 40 or even 60 year useful lifespan). This however may not be fully be accurate in practice because of all the other effects over that time of the additional cumulative stressors like humidity, ozone, over temperature events (short circuit/overload) exposure to chemicals, light, mechanical stresses on fixings and supports, flexion and possibly even additional radiation events.

It is not commonly realized just how quickly common polymeric cable insulations can degrade with time and temperature when operated continuously in air at their rated temperatures:

Insulation Material	*Normal Temperature Rating*	*Continuous exposure for 20,000 hours (2.3 yrs) at rated temp.*	*Typical percentage reduction in elongation at break*
XLPE	90°C	90°C	75%
PVC	75°C	75°C	80%
EPR, CSP,	90°C	90°C	85%

Values can be vary depending on material compounds used

This differs very significantly from a 25% "change in any one original material property" and lends weight to the argument for a review within the critical Nuclear Industry.

In normal practice, the use of IEC60216 for determining polymeric insulation temperature ratings by heat aging and elongation at break measurements with the subsequent calculations for determining cable current ratings is pragmatic only because circuits are not often sized exactly to maximum current demand. Full load current loading of cables circuits can be infrequent and the "averaged' operating temperature of cables over their lifetime may well be rather less than the maximum conductor temperature ratings quoted in the standards thus extending the useful cable life span to a reasonable time.

In defense of the mentioned standards for common domestic, commercial and industrial applications, to calculate polymeric cable current ratings based on any more conservative usage may require significantly larger conductor sizes having significant economic impact.

The question for owners, designers and Authorities within the Nuclear and Power Generation industry is:

"Is the protocol for determining useful lifespan of electrical cable insulations by aged Elongation at Break to '50% residual' appropriate (which as demonstrated above can allow degradation in this property of 80% or more) or should life span calculations for cable insulations within the Power Generation Industry be based on a maximum change in any one of the materials "original properties" (example to 50%) and not a 50% 'residual' EAB as often used today?"

It is critical that electrical design engineers understand the ageing characteristics of polymeric insulations when selecting cables for use in applications where long reliable life is needed. Examples given here may reference NASA radiation test thresholds for insulations but arguably a similar approach might be appropriate in the Nuclear and Power Generation Industry especially as failure could impact significantly more people than space/aerospace ever could.

MICC/MIMS cables as produced today by TRM & MICC Ltd are made exclusively from inorganic materials so they do not age like polymeric cables and can offer a practical alternative to design engineers.

For the Power Generation Industry, electrical cable performances over long periods of time are absolutely essential. Applying the same EAB thresholds for determining expected life span of cable polymers as we do for non-critical domestic and commercial installations is at best questionable.