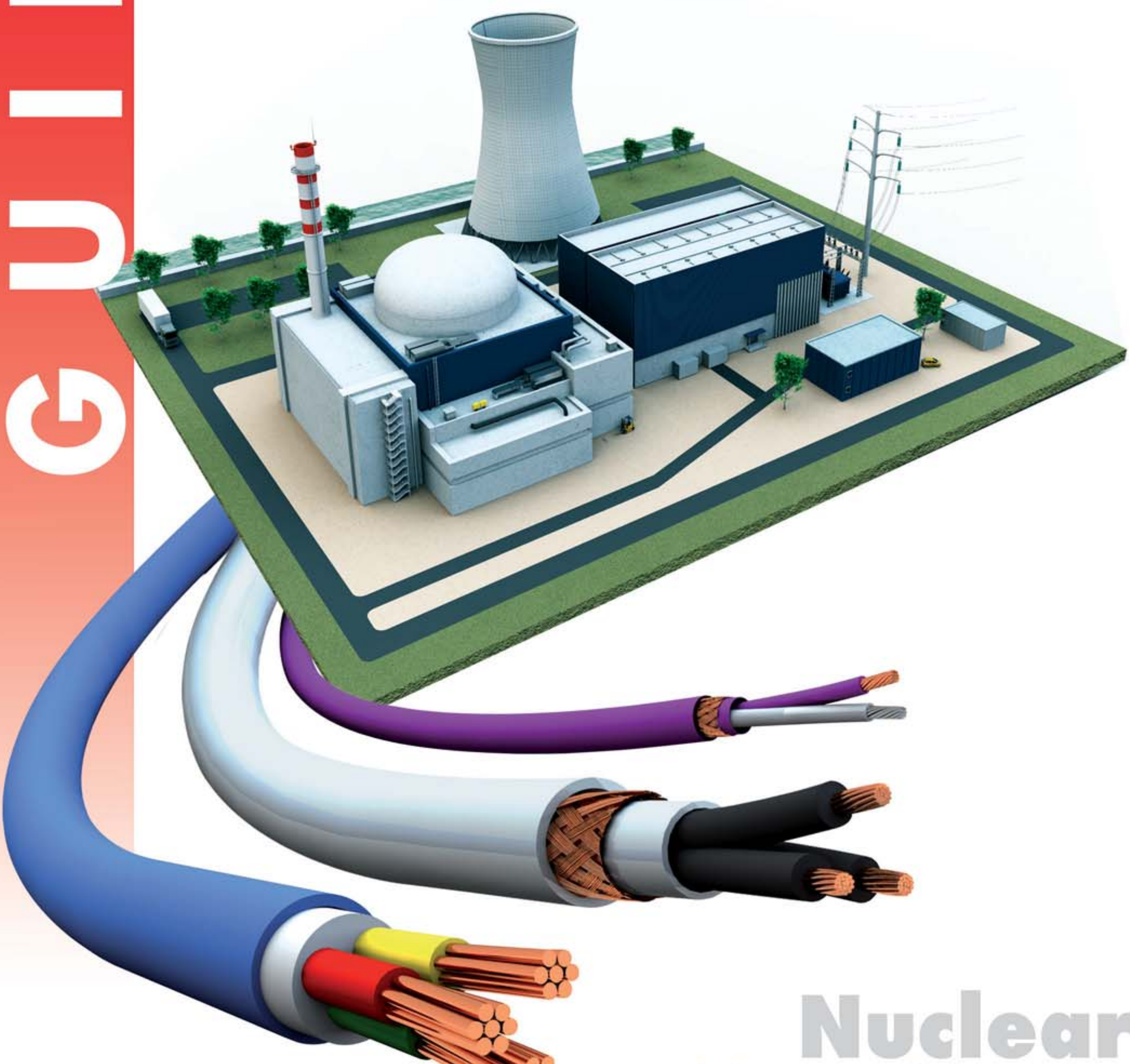
GUIDE

Nexans



Nuclear

Cable applications
Nuclear industry

Impacts
Cable mechanical resistance to impacts

Electro Magnetic Interference

Temperature
Permissible ambient temperature

Life time sixty years

Flame - Fire
Cable fire performances

Halogen free

Smoke

Lead free

Toxicity

Bending Radius
R = n x cable diameter

Corrosivity

Flexibility

Chemical attacks
Resistance to chemicals

Resistance to termite

Nexans

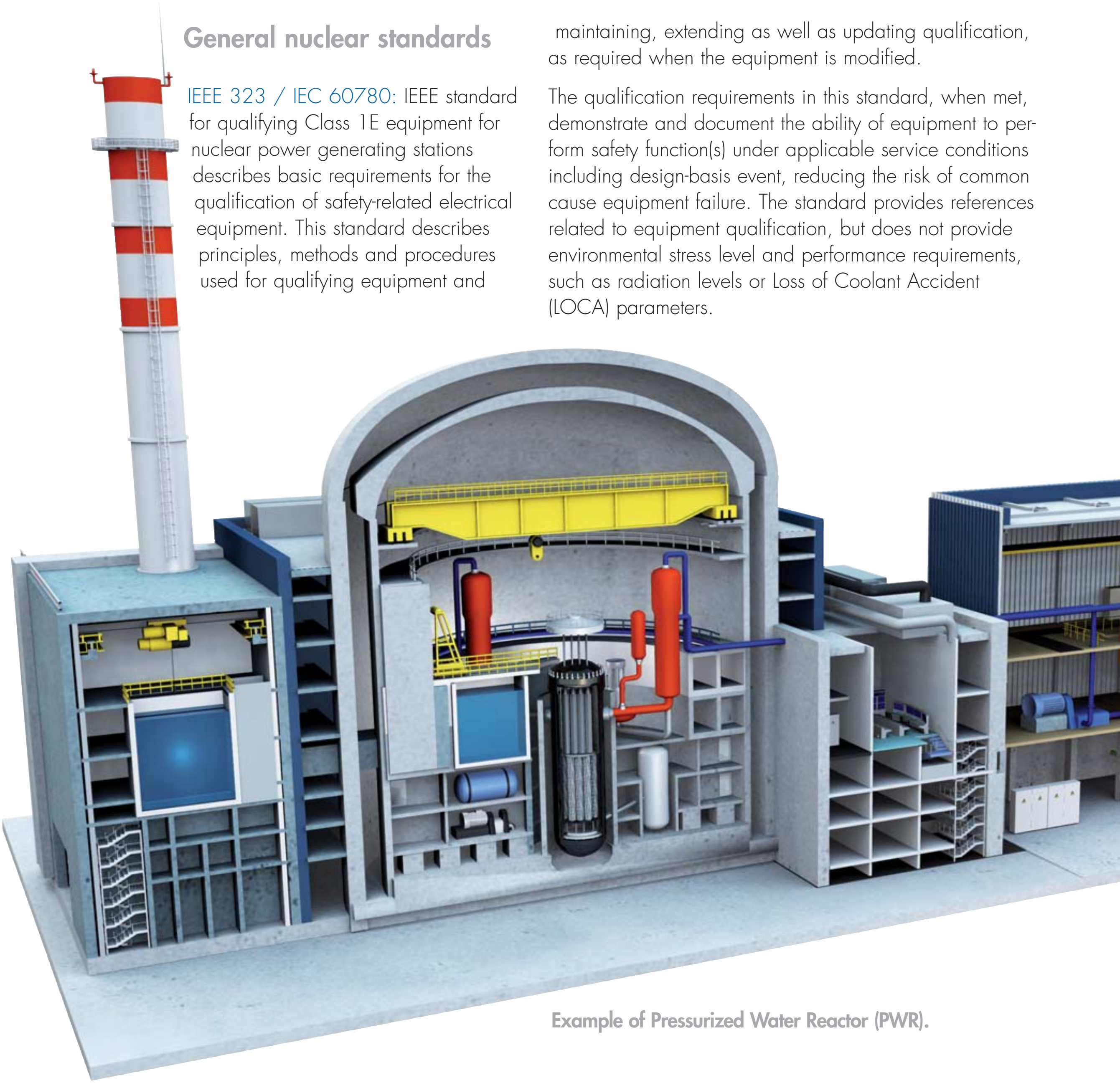
Cable applications guide
Nuclear industry

NUCLEAR EQUIPMENT STANDARDS

General nuclear standards

IEEE 323 / IEC 60780: IEEE standard for qualifying Class 1E equipment for nuclear power generating stations describes basic requirements for the qualification of safety-related electrical equipment. This standard describes principles, methods and procedures used for qualifying equipment and maintaining, extending as well as updating qualification, as required when the equipment is modified.

The qualification requirements in this standard, when met, demonstrate and document the ability of equipment to perform safety function(s) under applicable service conditions including design-basis event, reducing the risk of common cause equipment failure. The standard provides references related to equipment qualification, but does not provide environmental stress level and performance requirements, such as radiation levels or Loss of Coolant Accident (LOCA) parameters.



Example of Pressurized Water Reactor (PWR).

IEEE 383: IEEE standard for qualifying Class 1E electric cables and field splices for nuclear power generating stations provides general requirements, directions and methods for qualifying Class 1E (safety related) electrical cables, field splices and factory splices in nuclear power generating stations.

It encompasses power, control and instrumentation cables, including those used for signalling and communication.

The purpose of the standard is to provide specific directions for the implementation of IEEE 323 as it pertains to the qualification or electrical cables and field splices. IEEE 383 requires that safety-related cables and splices meet or exceed specified performance requirements throughout their installed life, and be subjected to a quality assurance program that includes design, qualification and production quality control.

The standard specifies methods of qualification applicable to various types of Nuclear Power Plants (NPP). Plant-specific parameters such as radiation levels and LOCA are not provided.

The vertical flame test procedure described in IEEE 383(1974) has been replaced by references to IEEE 1202. Qualification methods for splices have been removed. They are now included in IEEE 572.

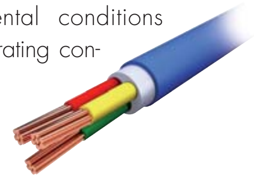
Other national standards also come into play, such as RCC-E wherever Electricité de France (EDF) is involved, DIN VDE in Germany, and the GOST standard in Russia, as well as GB standards in China.

Cable design and construction

Cables are designed according to standards which specify requirements for power, control, thermocouple, and instrumentation cables. Currently, standards also determine final characteristics of cables, following their end-uses, or refer to other national and international standards for properties like resistance to ageing and radiation, LOCA tests, mechanical properties or fire performance.

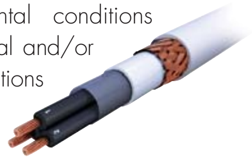
1E Non LOCA / K3 cables

Equipment installed outside of the containment area, capable of functioning under environmental conditions corresponding to normal plant operating conditions and under seismic load.



1E LOCA / K1 cables

Equipment installed inside of the containment area, capable of functioning under environmental conditions corresponding to normal, accidental and/or post-accidental plant operating conditions and under seismic load.



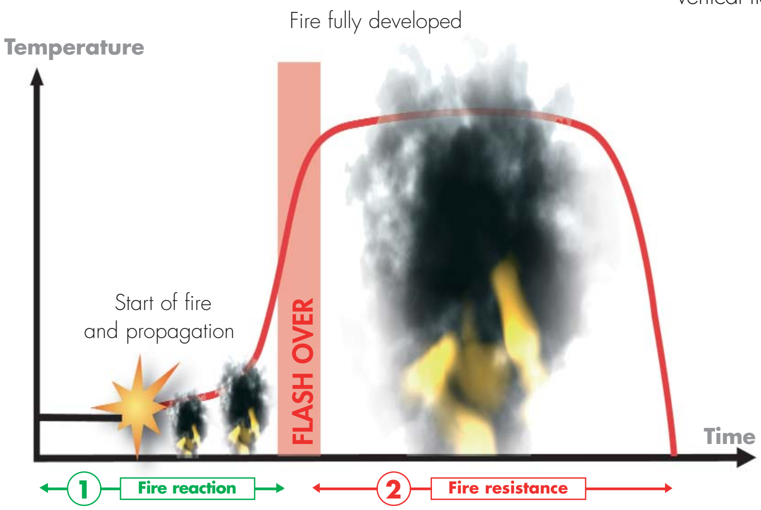
International standards requirements

International	USA	UK	France	Germany	Russia	China	Korea
IEC	ICEA	BS	CST	DIN	GOST	GB	KR
EN	UL		RCC-E	VDE			
	IEEE		NF				

FIRE BEHAVIOUR OF CABLES

Fire - reminders

For a fire to form and spread, three elements must be present: combustible material, oxygen, and a heat source. There are two main phases in the development of a fire:
- The initial spreading phase, when the fire spreads slowly and can be kept under control.
- The combustion phase when it can no longer be kept under control. The transition between the two phases is called the Flash Over Point (see figure below).



Fire behaviour of cables

The cables are classified according to:

- **The fire reaction** (1), i.e. their role as passive elements during a fire characterized by flammability, fire spread, heat release, smoke emission and toxicity.

- **The fire resistance** (2), i.e. their role as active elements characterized by electrical continuity under fire conditions.

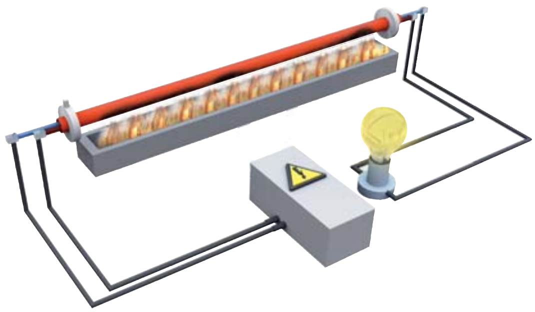
Standards and tests

Fire reaction (1)

The burning behaviour of cables is determined by tests defined by IEC 60332-1, EN 50265 in terms of flame retardant properties and IEC 60332-3 (cat. A, B, C and D), EN 50266-2 or IEEE 1202 for fire retardant performance. Cables are qualified during these tests according to their vertical flame spread resistance.

Fire resistance (2)

The fire resistance of cables is characterized by tests defined by the IEC 60331 or EN 50200.

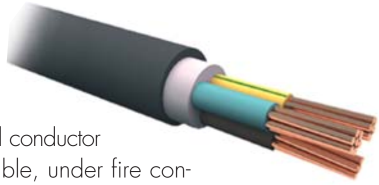


Cables are qualified according to their resistance to fire and other combined parameters, such as mechanical shocks and water spray. These tests are carried out on cables under electrical load.

Fire properties

Fire propagation performance

IEC 60332-1 - Tests for vertical flame propagation for a single insulated wire or cable

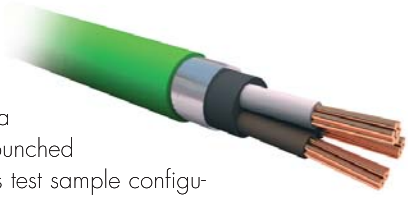


This standard defines the procedure for testing the resistance to vertical flame propagation for a single vertical electrical insulated conductor or cable, or optical fibre cable, under fire conditions. Flame shall be applied continuously for period of time corresponding to diameter of tested piece of cable, having initial length of 600 ± 25 mm.
Recommended performance requirements: Cable shall pass the test if the distance between the lower edge of the top support and the onset of charring is greater than 50 mm.

UL 2556 §9.3 (FT1) or §9.4 (VW-1) Burning characteristics tests.

This standard describes vertical flame propagation tests for single insulated wire. The flame is applied 5 times for 15 sec. A kraft paper indicator flag fixed 254 mm above the flame shall not catch fire for the test to pass.

IEC 60332-3 (cat. A, B, C and D) - Tests for vertical flame spread on vertically mounted bunched wires or cables



Various categories are defined in IEC 60332-3-10.
This standard defines a series of tests where a number of cables are bunched together to form various test sample configurations. For easier use and differentiation of various test categories, the parts are designated as follows:

Standard	Category	Flame application time	Volume of non metallic material
IEC 60332-3-22	A	40min.	7.0l
IEC 60332-3-23	B		3.5l
IEC 60332-3-24	C	20min.	1.5l
IEC 60332-3-25	D		0.5l

IEEE 1202: IEEE standard for Flame testing of Cables for Use in Cable tray in Industrial and Commercial Occupancies

IEEE standard for flame testing of cables for use in cable trays in industrial and commercial occupancies. It provides a protocol for exposing cable samples to a 20 kW flame ignition source for 20 minutes. The test determines the flame propagation tendency of single conductor and multiconductor cables intended for use in cable trays, installed either horizontally or vertically, in industrial and commercial occupancies. The IEEE 1202 test can include smoke measurement as an option. The smoke test option is described in UL1685.

Fire resistance performance

- Circuit integrity must be maintained when cables are subjected to fire under specified conditions. It includes the standard procedure for checking continuity as well as evaluating test results for low voltage power cables and control cables with rated voltage.
Depending on which section of the standard is referenced, two different temperatures are used for fire resistance assessment 750°C (IEC 60331-11) or 830°C (IEC 60331-12).
Cable has to show electrical continuity, i.e. its ability to continue to operate in the designated manner whilst subjected to a specified flame source for a specified period of time (90 minutes flame application is recommended).

Smoke and gas emissions

Human impact

Smoke can be more dangerous than the fire that creates it, due to its opaque and toxic nature.
Cables are a critical component because they are present throughout the entire facility. During a fire, they can increase emissions of dense, corrosive and toxic smoke.
In order to greatly reduce the amount of emissions, as well as their toxicity and corrosivity, materials which do not contain halogens, known as Halogen Free Fire Retardant (HFFR) or Low Smoke Zero Halogen (LSOH) can be used for both cable insulation and sheath.

IEC 61034 provides details about the test procedure for the measurement of the density of smoke emitted from cables burning under defined conditions. It describes the means of preparing and assembling cables for testing, the method for burning the cables, and gives recommended requirements for evaluating test results.

UL 1685 smoke test:

As already mentioned above (page 7), the UL1685 fire propagation test can include the option of measuring the emitted smoke quantity. The smoke is measured by an optical system recording light attenuation across the exhaust tube of the enclosure.
Additionally, testing the smoke properties of cable material can be obtained with the following test:

ASTME E 662: NBS Smoke density chamber

Several methods are based on the NBS Smoke Density Chamber such as IEC 60695-6-30, ISO 5659-2, BS 6401, NF C 20902-1, NF C 20902-2, ASTM E 662 and NFPA 258. The attenuation caused by smoke accumulation in the test chamber is measured. The smoke is generated by pyrolysis (smouldering combustion) or combustion (flaming conditions). Results are expressed as specific optical smoke density (Ds) derived from a geometric factor and the measured optical density, a measurement characteristic of the concentration of smoke (VOF4).

Fire properties

IEC 60754-1 - Test on gases emitted during combustion of electric cables - Determination of the amount of halogen acid gas

Standard IEC 60754-1 specifies a method for the determination of the amount of halogenic acid gas, other than hydrofluoric acid, emitted during the combustion of compounds based on halogenated polymers and compounds containing halogenated additives taken from cable construction. This method is not recommended for use where the amount of halogenic acid emitted is less than 5 mg/g in the sample taken.

IEC 60754-2 - Determination of degree of acidity of gases emitted during combustion of electric cables by measuring pH and conductivity

Standard IEC 60754-2 specifies a method for the determination of the degree of acidity of gases emitted during the combustion of compounds taken from cable components. It encompasses both procedure and monitoring of the samples.

UL 2556 §9.10 Halogen acid gas emission and UL 2556 §9.11 Acid gas emission describe test methods for evaluating the same properties.

SPECIFIC NUCLEAR POWER PLANT REQUIREMENTS

Safety is the main concern in Nuclear Power Plant (NPP) design. The operator must be able to shut down the reactor in a controlled way in all hypothetical conditions and prevent any release of radioactive material. The required equipment must be qualified to resist these conditions, even under the most severe accident scenarios.

Cables, in particular, must continue to operate numerous 1E systems, such as pumps, valves, engines and all kinds of essential measurement equipment for pressure, temperature, radiation etc. Special cable qualification procedures to severe irradiation and hot steam/water at high pressure are applied. In addition to qualification procedures prior to installation, cables will undergo mandatory condition monitoring on site to ensure sustained performance over time.

1E classified equipment = Safety classified equipment

Safety classification systems

In order to classify safety related equipment, different systems exist in different countries. Examples are given in the table below.

Safety classification systems	Safety classified		Not safety classified
American	1E		Non 1E
	1E LOCA	1E non LOCA	
Russian	K0, K1, K2	K3	
Korean	Q	R	
French	K1	K3	Non classified

ACCELERATING AGEING

It is extremely important for cables to be resistant to degradation over time, to be able to fulfill their expected safety function over the full lifetime of the power station. In case of insufficient lifetime, cables cannot be replaced as easily as other equipment, because they are often installed in inaccessible or sealed areas. Therefore, cable replacement would mean very long outage times and is not an alternative to very good ageing properties.

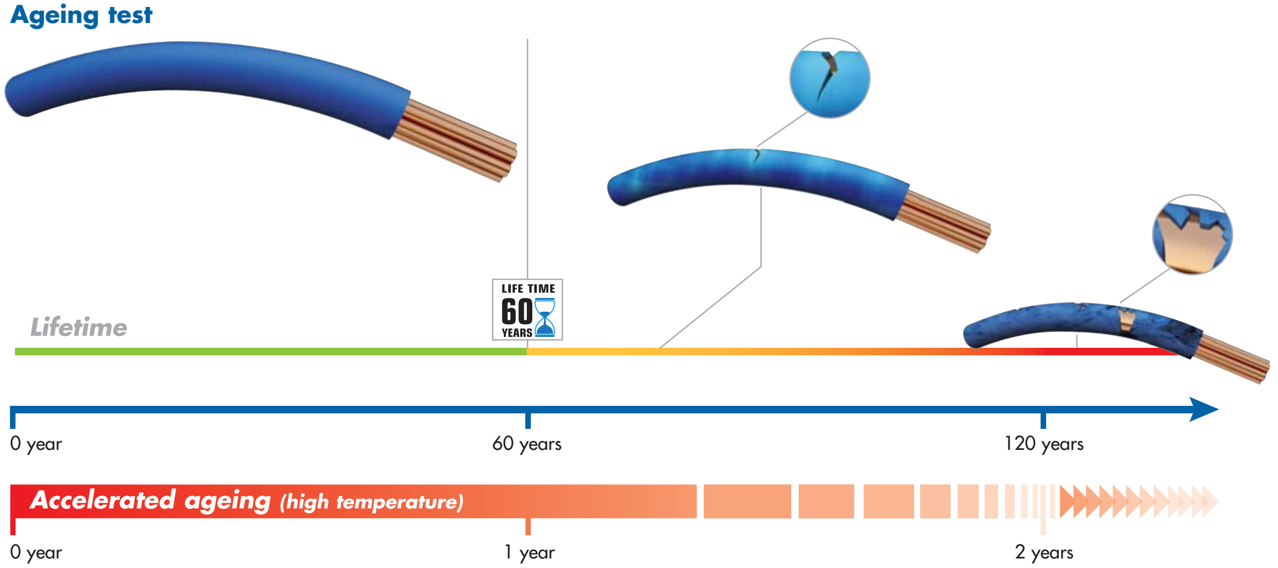
Therefore, Nexans NPP cables comply with the industry expected lifetime of 60 years.

To ensure ageing resistance, cables are exposed to artificial ageing procedures that reproduce the actual damage done to cables over time. For cables outside of the reactor core, the most important concern is degradation of polymers due to oxidation. Since oxidation is caused by ambiant air, and accelerated by heat, the ageing tests are conducted by exposing the cables to very high temperatures. Additionally, cables have to resist high levels of radiation.

LIFE TIME 60 YEARS

Compliance with safety class requirements has to be demonstrated for the entire expected lifetime of the reactor. Therefore testing must be done by accelerated ageing methods, representing the design lifetime of the NPP (now 60 years).

Nuclear requirements



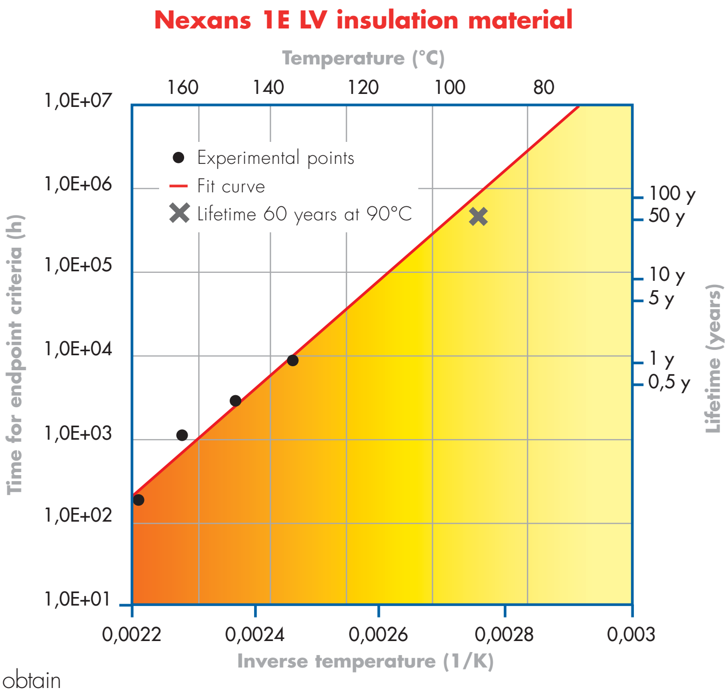
Thermal ageing

Ageing refers to a loss of certain properties over time. Polymers are particularly sensitive to ageing.

Thermally induced oxidation is one of the most damaging factors for polymers. Oxygen reacts with the polymer chains, making the polymer hard and brittle. This process is strongly correlated with temperature. Thermally activated ageing can be described according to various empirical models, the most well-known being the Arrhenius model.

The Arrhenius model gives a law to extrapolate expected lifetime at low temperature from experimental data obtained at high temperature in a relatively short period of time. According to this model, the logarithm of the lifetime is a linear function of the inverse absolute temperature (1/Kelvin).

Arrhenius test results are used to define specific accelerated ageing test conditions for the whole cable, representing the expected lifetime. For non LOCA cables, the evaluation stops here. For LOCA cables, the tests on the next pages are conducted. To obtain good ageing resistance, Nexans R&D laboratories have developed, tested and applied special polymer formulations.



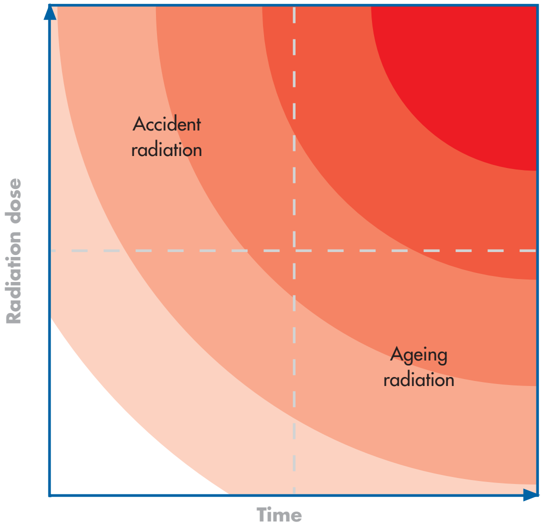
RADIATION

Radiation Ageing and Accident Radiation

Radiation can cause and accelerate the same degradation as thermal ageing, especially if the cables are exposed to air. Depending on three main parameters, dose rate, integrated dose and temperature, polymers can become hard and brittle.
The dose absorbed by the cable varies depending on its location within the reactor building. It remains low under normal operating conditions. To check a cable's resistance during an accident, much higher doses are applied during the qualification process (see below).

In case of an accident, cables must resist strong radiation with both high dose rate and high integrated dose.

Cables' resistance to both ageing and radiation is tested with a single cumulative dose of up to 2,000 kGy, depending on reactor design. This dose is very high compared to a lethal dose for humans of about 0.005 kGy.



LOSS OF COOLANT ACCIDENT (LOCA)

A nuclear plant's safety relies on the safe transfer of heat produced within the reactor vessel to the environment. Most reactor cooling circuits use water as their cooling fluid.

One of the most severe accident scenarios involves a leak in the primary cooling circuit.

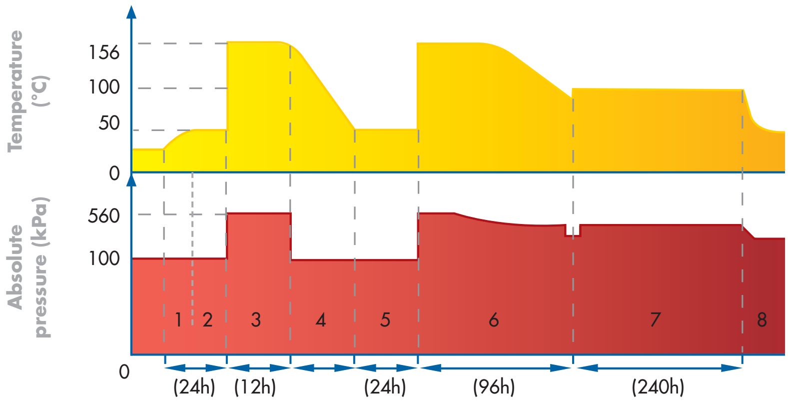
Under this type of scenario, large quantities of radioactive water at high temperature are released within the reactor containment, resulting in high pressure, temperature and radiation. Design-specific emergency cooling and shutdown systems then reduce temperature and pressure until they return to nominal levels. In the meantime, safety-related equipment must continue to operate. Cables qualified to 1E LOCA ensure power is delivered to the equipment and instrument readings are fed back to the control room under these conditions.

Scenarios of this type are called :
- **LOCA** = Loss Of Coolant Accident (most common)
- **DBA** = Design Base Accident
- **HELB** = High Energy Line Break
- **MSLB** = Main Steam Line Break

Nuclear requirements

The precise LOCA scenario depends on reactor type, location in the reactor and the actions/reactions of the safety systems.

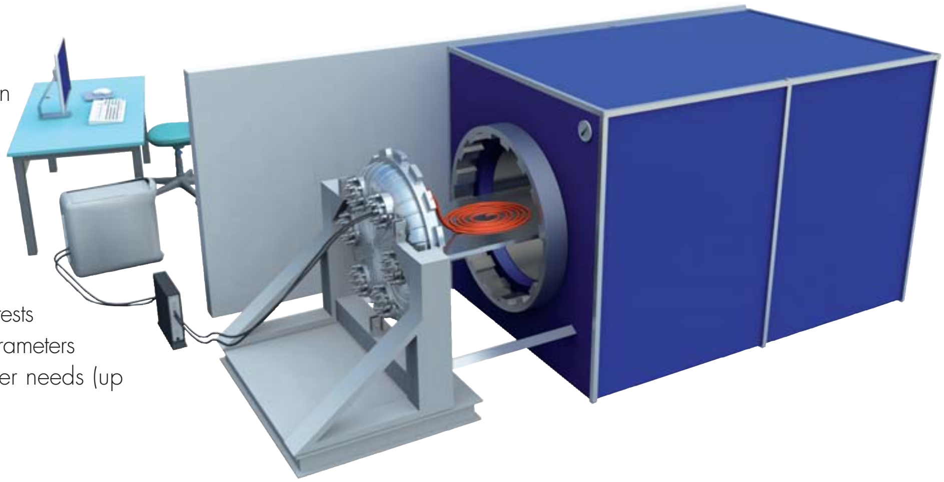
An example of LOCA curves are given in the following figure.

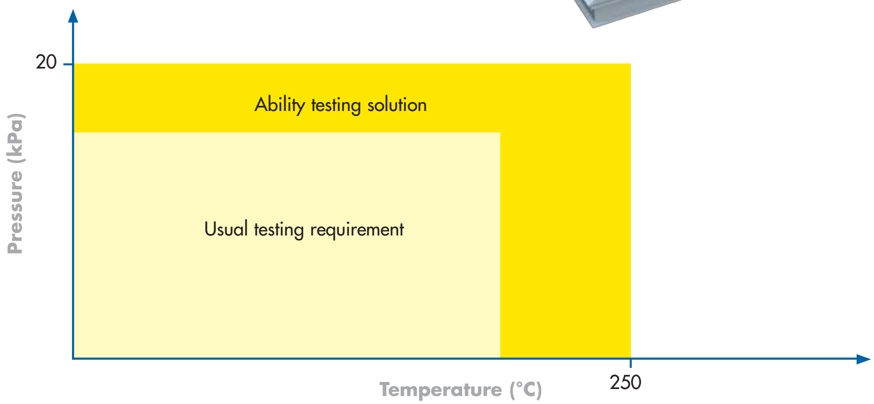


The figure shows the LOCA curve used for the French PWR.
It has a double peak for pressure and temperature and has particularly long duration. In phase 6 the samples are sprayed with deactivation solution (boric acid).

NEXANS SOLUTION

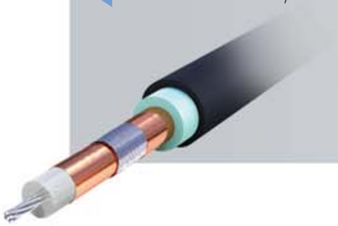
These LOCA tests are done in specially equipped auto-claves, allowing the application of prescribed scenarios to the cable samples. Nexans is equipped with its own auto-clave, and is able to do the tests beyond the usual specified parameters to be ready for future customer needs (up to 250°C, and 20 bars).



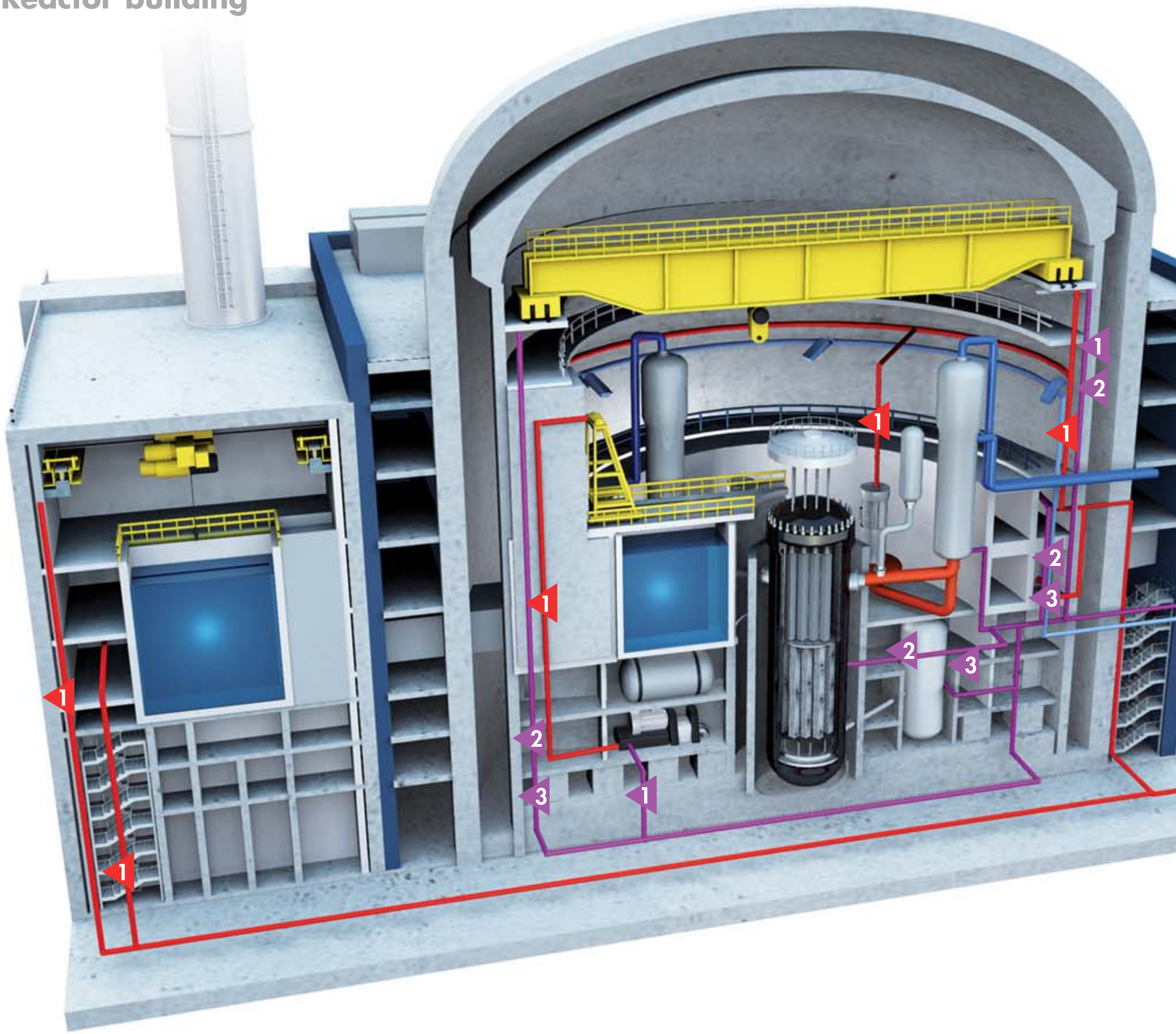


Communication / **Video** networks

1 Application examples:
For some special applications (detectors...) and for video networks, coaxial or multi-coaxial cables.



Reactor building



_Class 1E LOCA/K1 cables

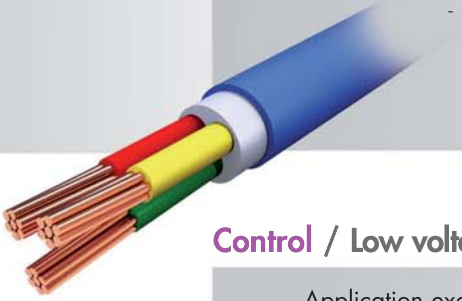
Energy / Medium voltage networks

Application examples:
- Medium voltage power supply (6/10 kV or 15kV)

Energy / Low voltage circuits

1

Application examples:
- Low voltage networks
  - Engine power supply
  - Solenoid valve power supply



Control / Low voltage control circuits

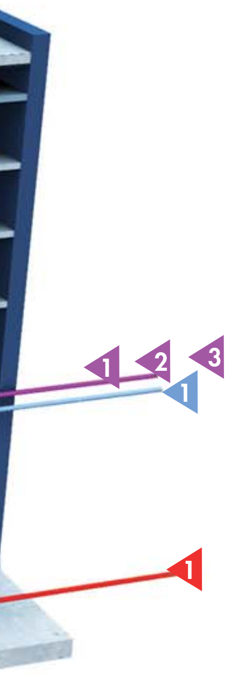
1

Application examples:
Connection to a variety of industrial equipment from control room. Many of them require anti-inductive screens (EMI).

Instrumentation / Measurement circuits

2

Application examples:
Connection to various types of measurement equipment. Can be multipairs, triads and quads. Generally, anti-inductive screen is required.



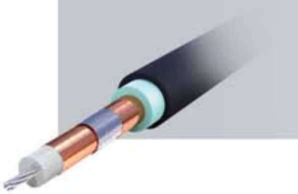
Compensation circuits

3

Application examples:
- Connection control board/process for temperature measurement
  - Thermocouple transmission signal

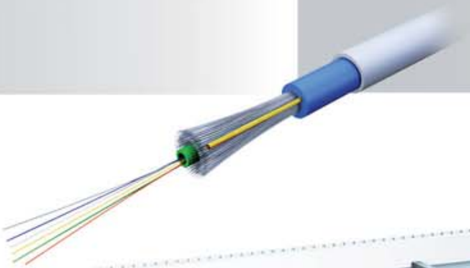
Cable characteristics
See selection table p.18

Communication / Video networks

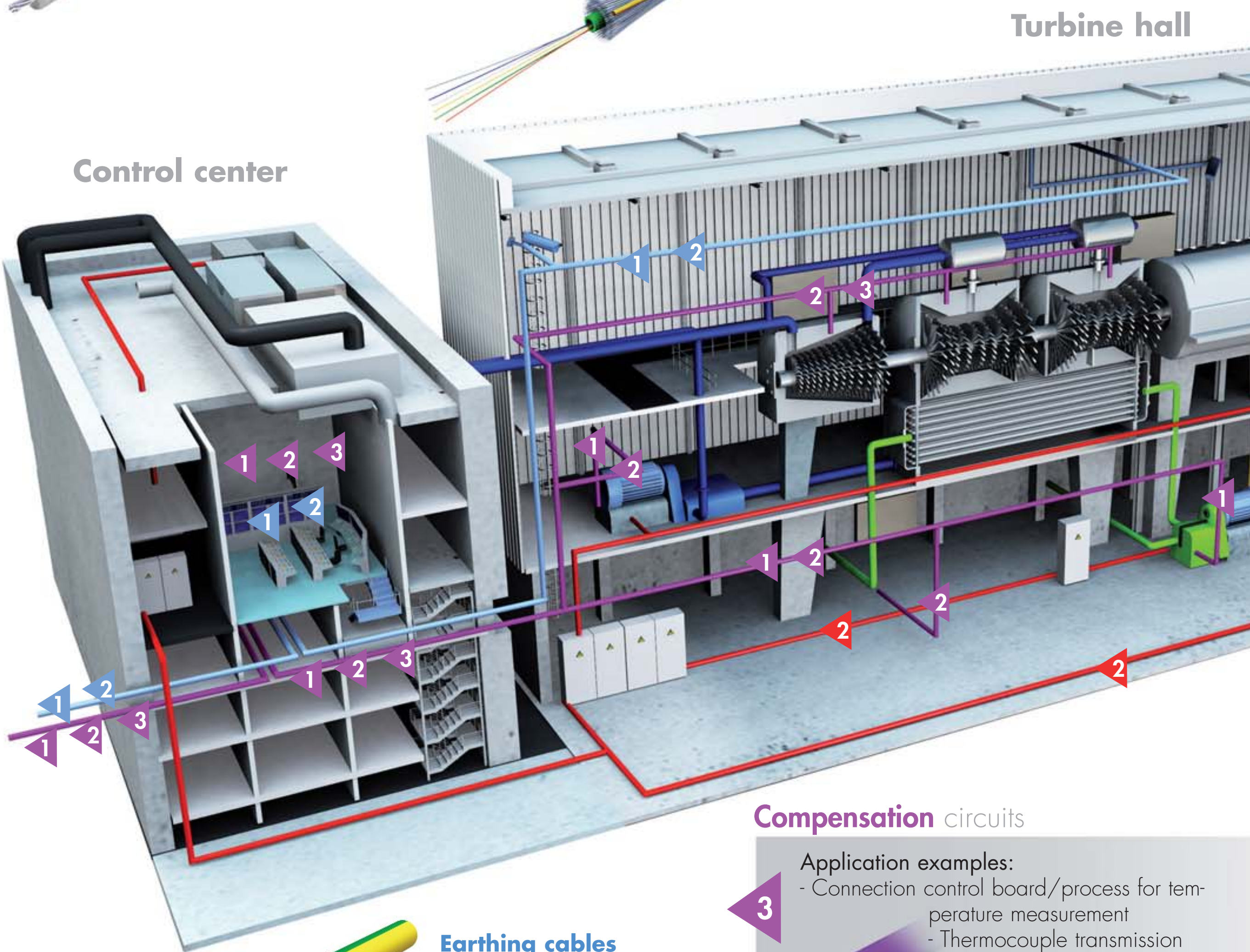


Application examples:
For some special applications (detectors...) and for video networks, coaxial or multi-coaxial cables.

Communication / Data and video networks



Application examples:
- Process zone data connection
- Video signal transmission

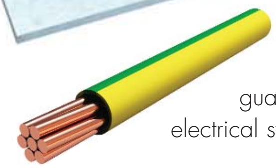


Compensation circuits

3

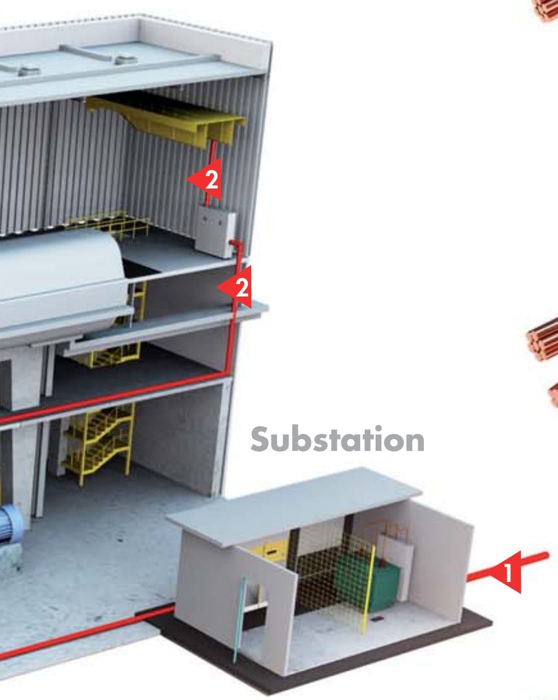
Application examples:
- Connection control board/process for temperature measurement
- Thermocouple transmission signal

Earthing cables



Cables are used to guarantee the integrity of electrical systems and the safety of personnel.

1E Non LOCA/K3 cables

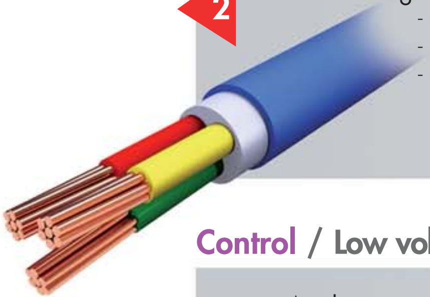


Energy / Medium voltage networks

Application examples:
- Medium voltage power supply (6/10 kV or 15kV)

Energy / Low voltage circuits

Application examples:
- Low voltage networks
  - Lighting system power supply
  - Engine power supply
  - Solenoid valve power supply



Control / Low voltage control circuits

Application examples:
Connection to a variety of industrial equipment from control room. Many of them require anti-inductive screens (EMI).

Instrumentation / Measurement circuits

Application examples:
Connection to various measurement equipments. Can be multipairs, triads and quads. Generally, anti-inductive screen is required.

Cable characteristics
See selection table p.18

For any further information: www.nexans.com

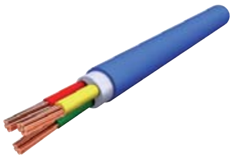
Class 1E LOCA Cables

Medium Voltage Power cables

Function	Rated voltage	Radiation resistance	LOCA resistance	Conductor type	Design families	Fire performance
Medium voltage circuits	3,6/6 kV 6/10 kV 6/6(7,2) kV* 5 kV 8 kV 15 kV	yes	yes	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper Aluminium	CST 74C068 IEC 60502-2 ICEA S-94-649 AEIC CS6/8	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685

** non radial field*

Low Voltage Power cables



Function	Rated voltage	Radiation resistance	LOCA resistance	Conductor type	Design families	Fire performance
Low voltage circuits	0,6/1 kV 600 V	yes	yes	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper Aluminium Sector shaped (option)	CST 74C068 IEC 60502-1 ICEA S-95-658 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Fire resistant low voltage circuits	0,6/1 kV	yes	yes	See above	IEC 60502-1	+ IEC 60331
Earthing circuits	0,6/1 kV 600 V	yes	yes	See above	See above	See above

For any further information: www.nexans.com

Class 1E LOCA Cables

Low voltage Control and Measurement cables

Function	Rated voltage	Radiation resistance	LOCA resistance	Conductor type	Screen type	Design families	Fire performance
Control and Instrument circuits	0,6/1 kV	yes	yes	IEC 60228 ASTM B8 Copper Tinned copper	without	CST 74C068 IEC 60502-1	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1
Control and Instrument circuits	300/500V 600 V	yes	yes	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper	Copper braid, Tinned copper braid, Copper foil	CST 74C068 ICEA S-73-532 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Thermocouple and compensation cables	300/500V 600 V	yes	yes	IEC 60584 ANSI ISA MC96.1	Copper braid, Tinned copper braid, Copper foil	CST 74C068 ICEA S-73-532 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Fire resistant Control and Instrument circuits	0,6/1 kV 300/500V	yes	yes	See above	See above	IEC 60502-1	+ IEC 60331

Class 1E LOCA Cables

Coaxial cables

Function	Rated voltage	Radiation resistance	LOCA resistance	Conductor type	Screen type	Design families	Fire performance
Signal circuits, video	According to specific design	yes	yes	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper Silver coated copper	According to specific design	According to specific design	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1

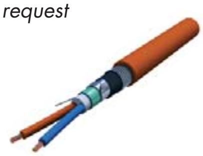
Class 1E Non LOCA Cables

Optical Fiber cables

Function	Fibre type	Design families	Fire performance
Optical signal circuits	62,5µm Multimode*	Glass yarn reinforced uni-tube*	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1

** other designs on request*

BUS cables



Function	Rated voltage	Conductor type	Screen type	Design families	Fire performance
On request					IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1

For any further information: www.nexans.com

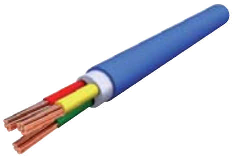
Class 1E Non LOCA Cables

Medium Voltage Power cables

Function	Rated voltage	Conductor type	Design families	Fire performance
Medium voltage circuits	3,6/6 kV 6/10 kV 6/6(7,2) kV* 5 kV 8 kV 15 kV	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper Aluminium	CST 74C068 IEC 60502-2 ICEA S-94-649 AEIC CS6/8	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685

** non radial field*

Low Voltage Power cables

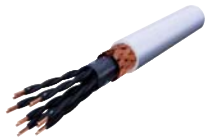


Function	Rated voltage	Conductor type	Design families	Fire performance
Low voltage circuits	0,6/1 kV 600 V	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper Aluminium Sector shaped (option)	CST 74C068 IEC 60502-1 ICEA S-95-658 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Fire resistant low voltage circuits	0,6/1 kV	See above	IEC 60502-1	+ IEC 60331
Earthing circuits	0,6/1 kV 600 V	See above	See above	See above

Selection table

For any further information: **www.nexans.com**

Low voltage Control and Measurement cables



Function	Rated voltage	Conductor type	Screen type	Design families	Fire performance
Control and Instrument circuits	0,6/1 kV	IEC 60228 ASTM B8 ASTM B33 Copper Tinned copper	Copper braid, Tinned copper braid, Copper foil, Aluminium polyester foil	CST 74C068 IEC 60502-1	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1
Control and Instrument circuits	300/500V 600 V	IEC 60228 ASTM B8 ASTM B33	Copper braid, Tinned copper braid, Copper foil, Aluminium polyester foil	CST 74C068 ICEA S-73-532 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Thermocouple and compensation cables	300/500V 600 V	IEC 60584 ANSI ISA MC96.1	Copper braid, Tinned copper braid, Copper foil, Aluminium polyester foil	CST 74C068 ICEA S-73-532 UL 44	IEC 60332-3-22 (A) IEC 60332-3-23 (B) IEC 60332-3-24 (C) NFC 32070 C1 IEEE 383 IEEE 1202 UL1685
Fire resistant Control and Instrument circuits	0,6/1 kV 300/500V	See above	See above	IEC 60502-1	+ IEC 60331

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