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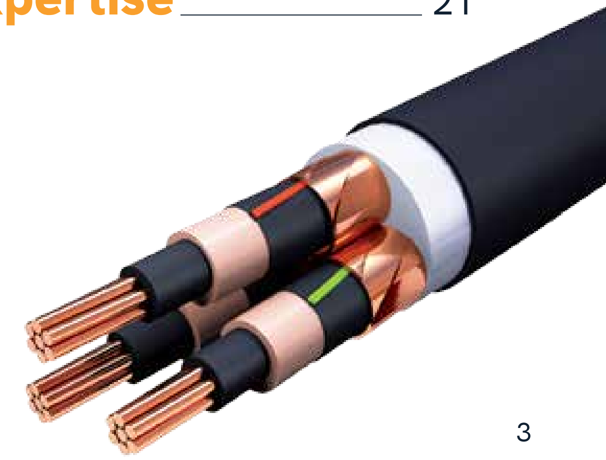
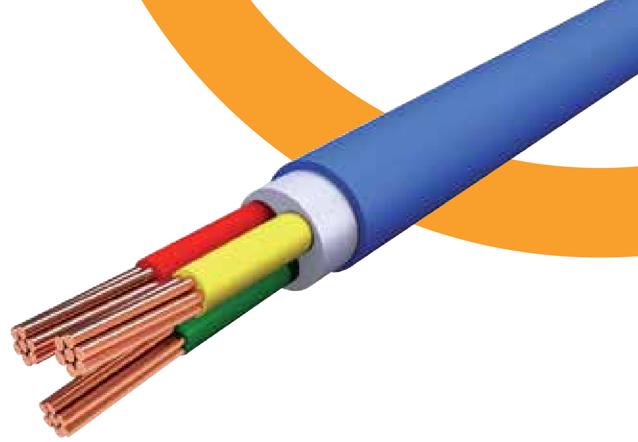


Nuclear energy



A Pillar of Global Clean and Reliable Power

Nuclear energy currently holds a significant position among electricity generation technologies. Globally, it provides about 9% of total electricity and stands as the second-largest source of low-emissions electricity after hydropower. While fossil fuels -particularly coal, natural gas, and oil – still dominate the global electricity mix at around 60%, nuclear energy is ahead of both wind and solar in terms of electricity output. Moreover, compared to wind and solar, nuclear energy provides stable and continuous power, contributing to energy security and grid stability.

Regionally, the importance of nuclear energy varies. For example, it accounts for about 65% of electricity in France, over 60% in the Slovak Republic, less than 20% in the United States, and is rapidly expanding in China, which leads in new reactor construction. Investments in nuclear technology have recently increased, reaching about $65 billion in 2023 – almost double the amount from a decade earlier – reflecting renewed global interest, particularly in emerging economies and in advanced nuclear designs such as small modular reactors.

According to the International Atomic Energy Agency (IAEA) and the International Energy Agency (IEA), the world is seeing a marked increase in nuclear project commitments and financing as countries pursue energy security, clean energy goals, and expand new nuclear capacity. In particular, the IEA's «World Energy Investment 2024» report highlights that the nuclear sector now requires annual investments of about $125 billion by 2050 to meet capacity goals, up from approximately $50 billion per year in the recent past. For the more ambitious target of tripling global nuclear capacity by 2050, annual nuclear investment would need to exceed $150 billion.

Regional developments underscore this upward trend: Europe is leading with new reactor projects, including France's first new reactor in 25 years and the UK's funding for both large nuclear power and small modular reactors (SMRs). Eastern European countries such as Poland, Romania, Bulgaria, and Lithuania are making substantial progress on new projects. In Asia, China continues to bring new reactors online, India is accelerating its nuclear program, and South Korea has reversed previous policies to support nuclear expansion. Additionally, several countries in Southeast Asia and Africa, such as Singapore, the Philippines, Egypt, and Ghana, are advancing nuclear plans or infrastructure.

The financing landscape is also evolving, with greater emphasis on innovative funding models and private sector involvement, as well as support from multilateral development banks, especially targeting developing nations. There is also growing global enthusiasm for SMRs and advanced modular reactors, which can serve a variety of roles beyond electricity, such as industrial heating.

In summary, nuclear energy is positioned as a cornerstone of low-carbon electricity production, combining reliability and significant emissions savings, and is expected to remain a central part of clean energy strategies worldwide, especially as investments in new nuclear technologies increase and more countries look to diversify their energy mixes with low-carbon solutions. 2024 is recognized as a pivotal year for a global revival in nuclear energy investment, marked by increased funding, more new projects, and supportive policy shifts positioning nuclear as an integral part of low-carbon energy strategies worldwide.

Sources:
IAEA Department of Nuclear Energy: Climate Change and Nuclear Power 2024 – Financing Nuclear Energy in low carbon transitions
IEA International Energy Agency: World Energy Investment 2024 – Analysis

Nuclear safety regulation

General Nuclear Standards

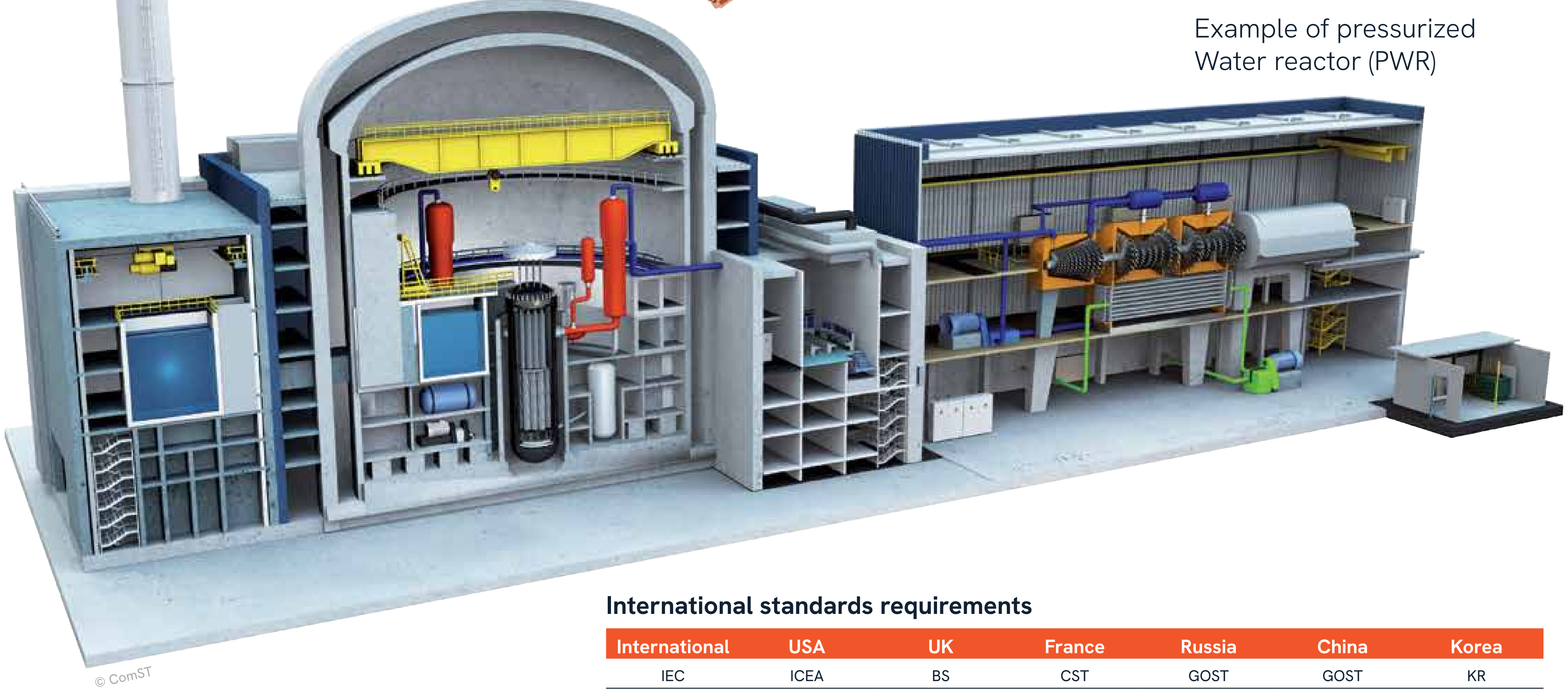
Nuclear regulation

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.

IEEE 383:
IEEE standard for qualifying Class 1E electric cables 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.

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 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.

Other national standards also come into play, such as RCC-E wherever Electricité de France (EDF) is involved, the GOST standard in Russia or China, as well as BS standards in UK.

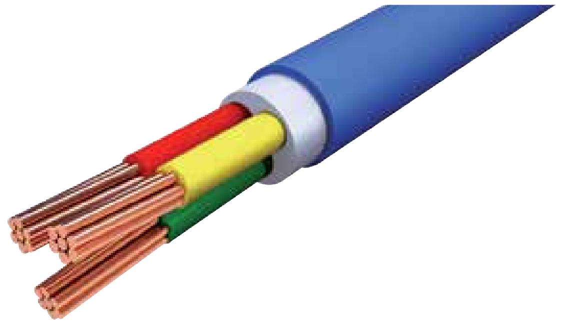


Example of pressurized Water reactor (PWR)

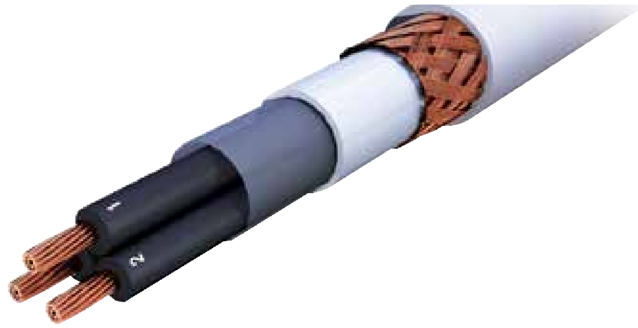
Cable design and construction

Cables are designed according to standards which specify requirements for power, control, thermocouple, and instrumentation cables. Currently, standards also determine 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.

Class 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



Class 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	Russia	China	Korea
IEC	ICEA	BS	CST	GOST	GOST	KR
EN	UL		RCC-E			
	IEEE		NF			

Nuclear safety regulation

Fire Reaction of Cables

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 the 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.

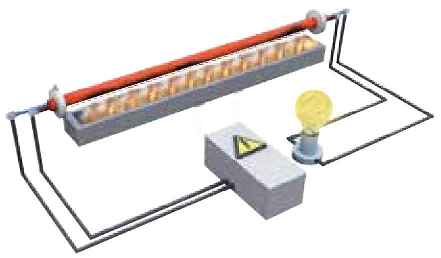
Standards and tests

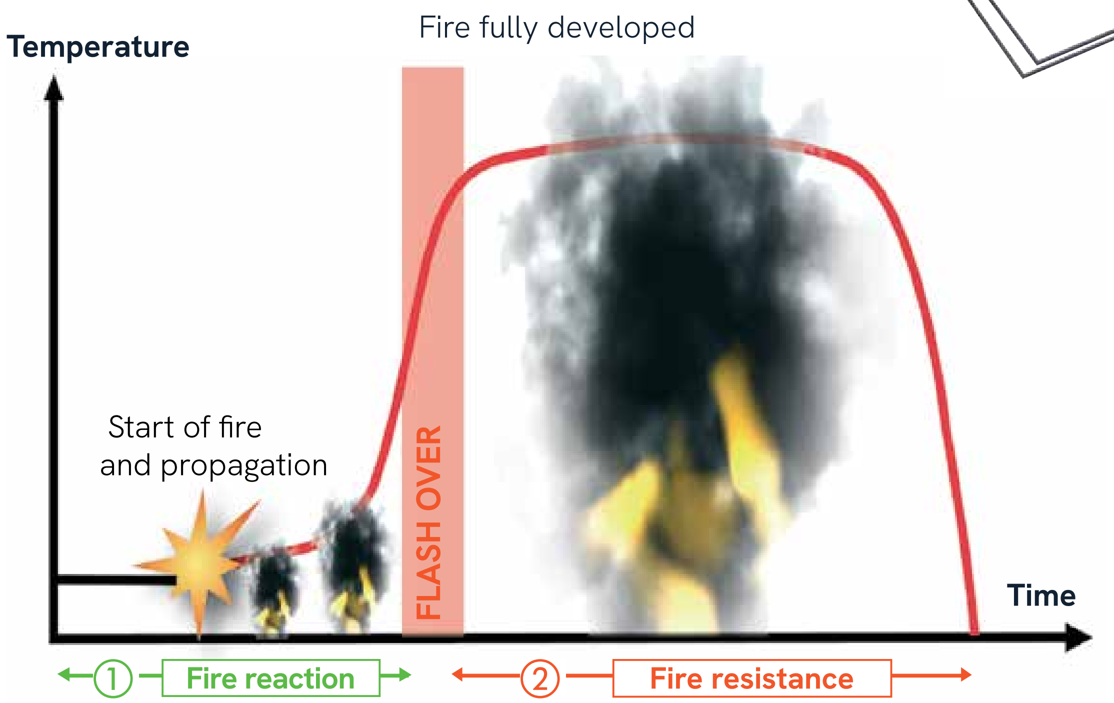
Fire reaction ①

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

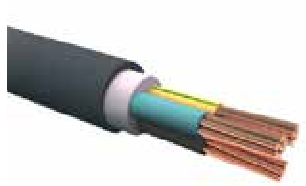
Fire resistance ②

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.



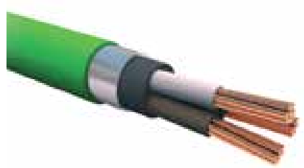


Fire propagation performance



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

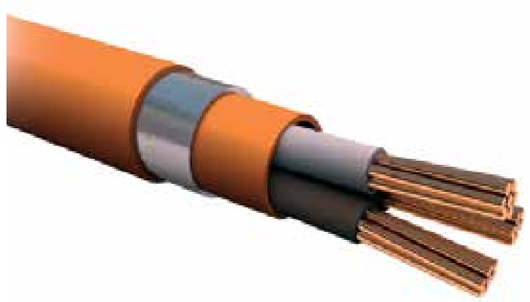
Various categories are defined in IEC 60332-3-10. This standard defines a series of tests where a number of cables are bunched together to form various test sample configurations. For easier use and differentiation of various test categories, the parts are designated as follows in the table below.

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 multi- conductor 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.

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

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. Over recent years, the reference standard for fire resistance has evolved from the IEC 60331-11/-21 tests conducted at 750°C to the more rigorous IEC 60331-1 & -2 standards at 830°C, which additionally include mechanical shock testing. 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 Low Smoke Zero Halogen (LSZH) 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 before, 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 ASTME E 662.

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).

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

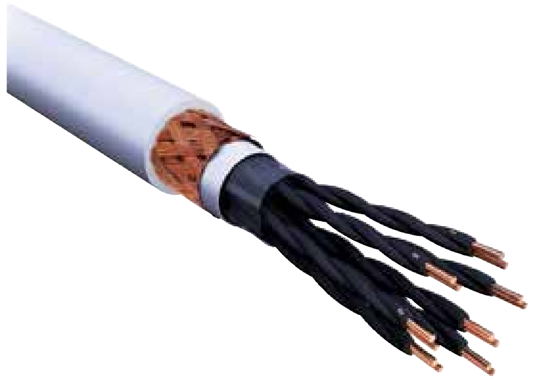
Standard IEC 60754-1 specifies a method for the determination of the amount of halogenic acid gas, other than hydrofluoric acid, emitted during the combustion of compounds based on halogenated polymers and compounds containing halogenated additives taken from cable construction. This method is not recommended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

Nuclear safety regulation

Ageing of Cable in Nuclear environment



Safety is the main concern in Nuclear Power Plant 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

Accelerated 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, Lynxeo ENERGEN® 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 ambient 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

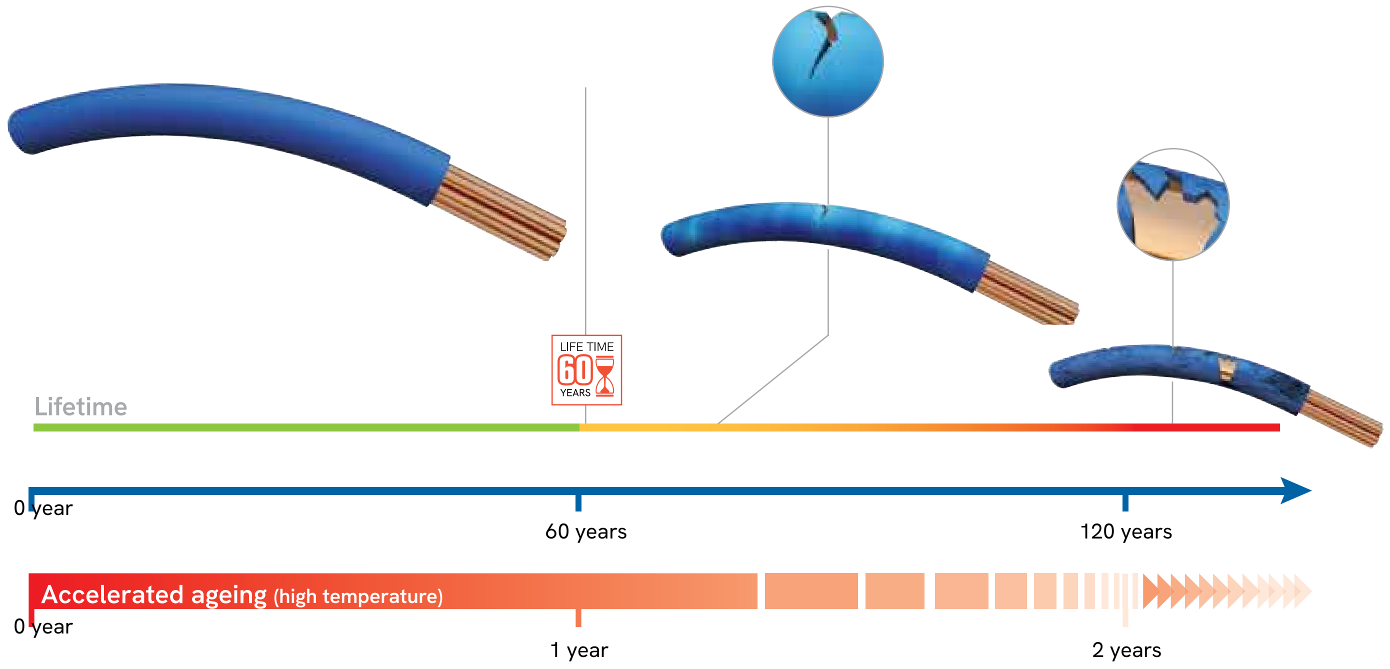
Compliance with safety class requirements has to be demonstrated for the entire expected lifetime of the reactor. Therefore testing must be done by accelerated ageing methods, representing the design lifetime of the NPP (now 60 years).

Safety classification systems

In order to classify safety related equipment, different systems exist in different countries as shown in the following table.

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

Ageing test

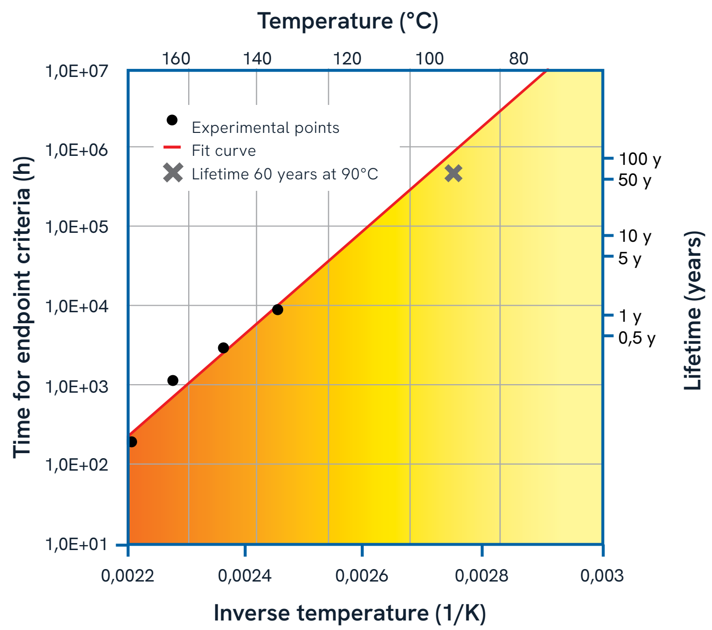


Thermal ageing

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, Lynxeo R&D laboratories have developed, tested and applied special polymer formulations.

Lynxeo 1E LV insulation material

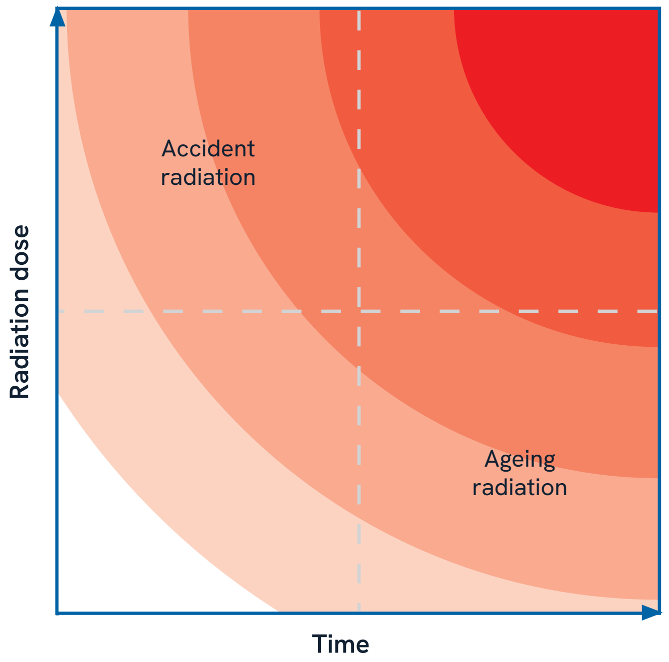


Radiation Ageing and Accident Radiation

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.

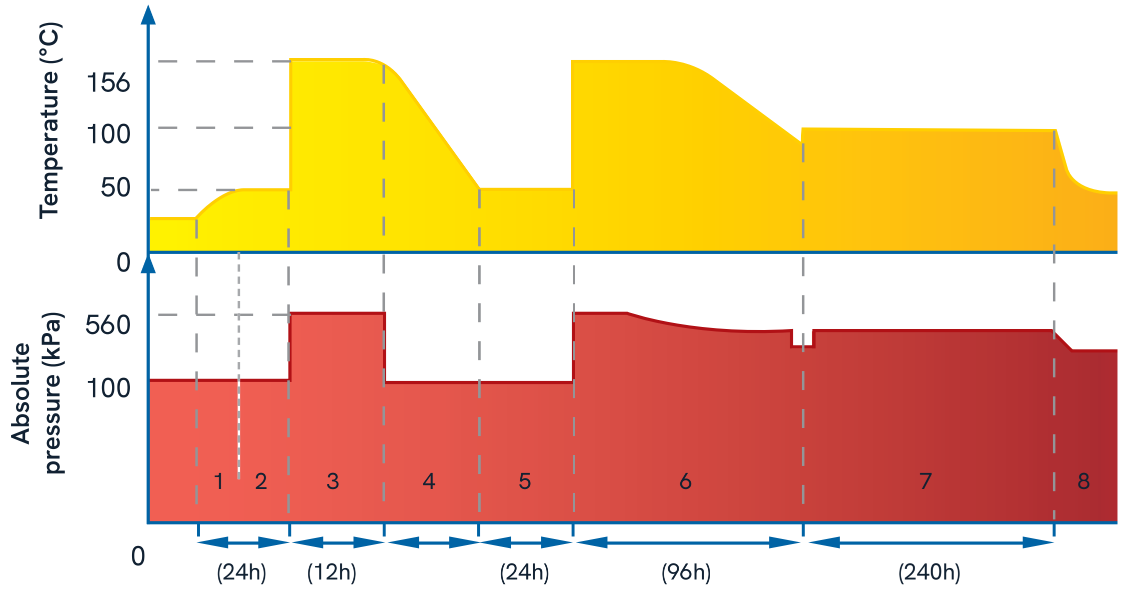
Design-specific emergency cooling and shutdown systems then reduce temperature and pressure until they return to nominal levels. In the meantime, safety-related equipment must continue to operate. Cables qualified to 1E LOCA ensure power is delivered to the equipment and instrument readings are fed back 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**

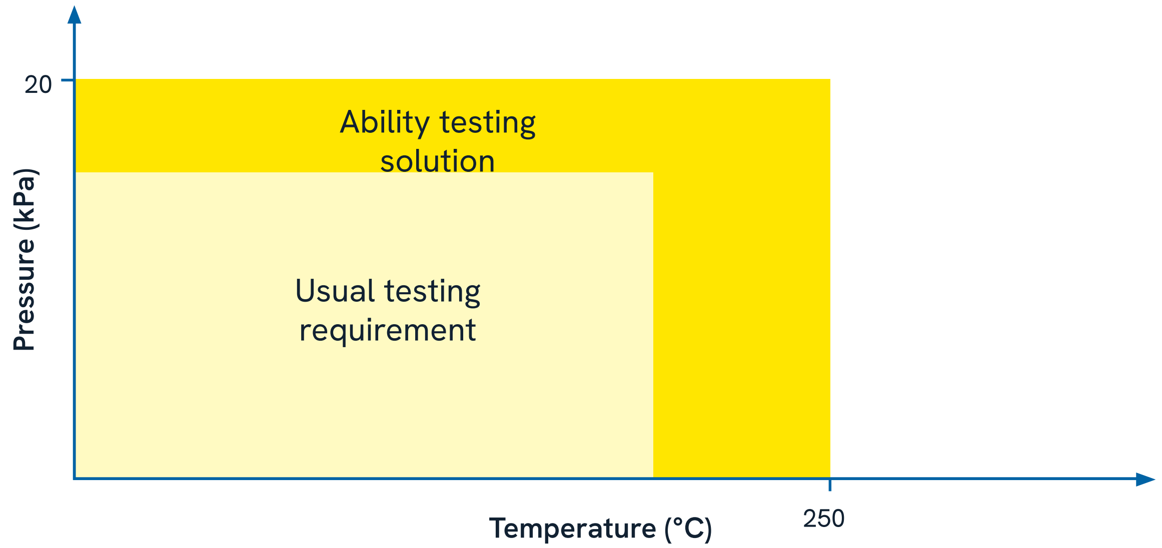
The precise LOCA scenario depends on reactor type, location in the reactor and the actions/reactions of the safety systems.

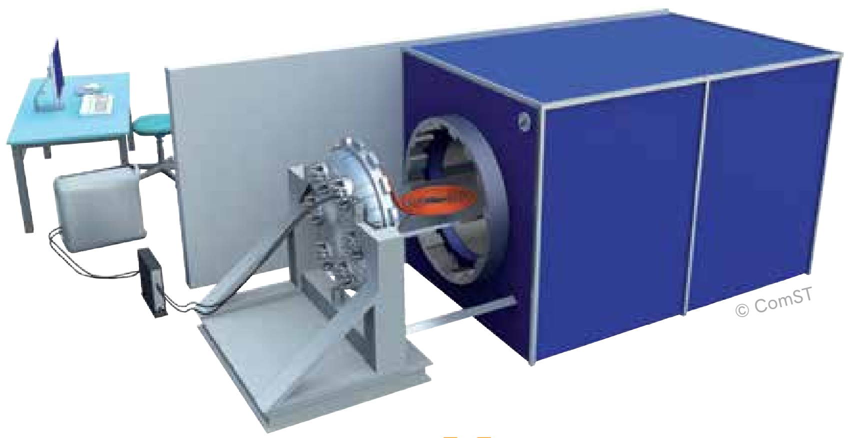
An example of LOCA curves are given in the following figure.



Lynxeo' solution

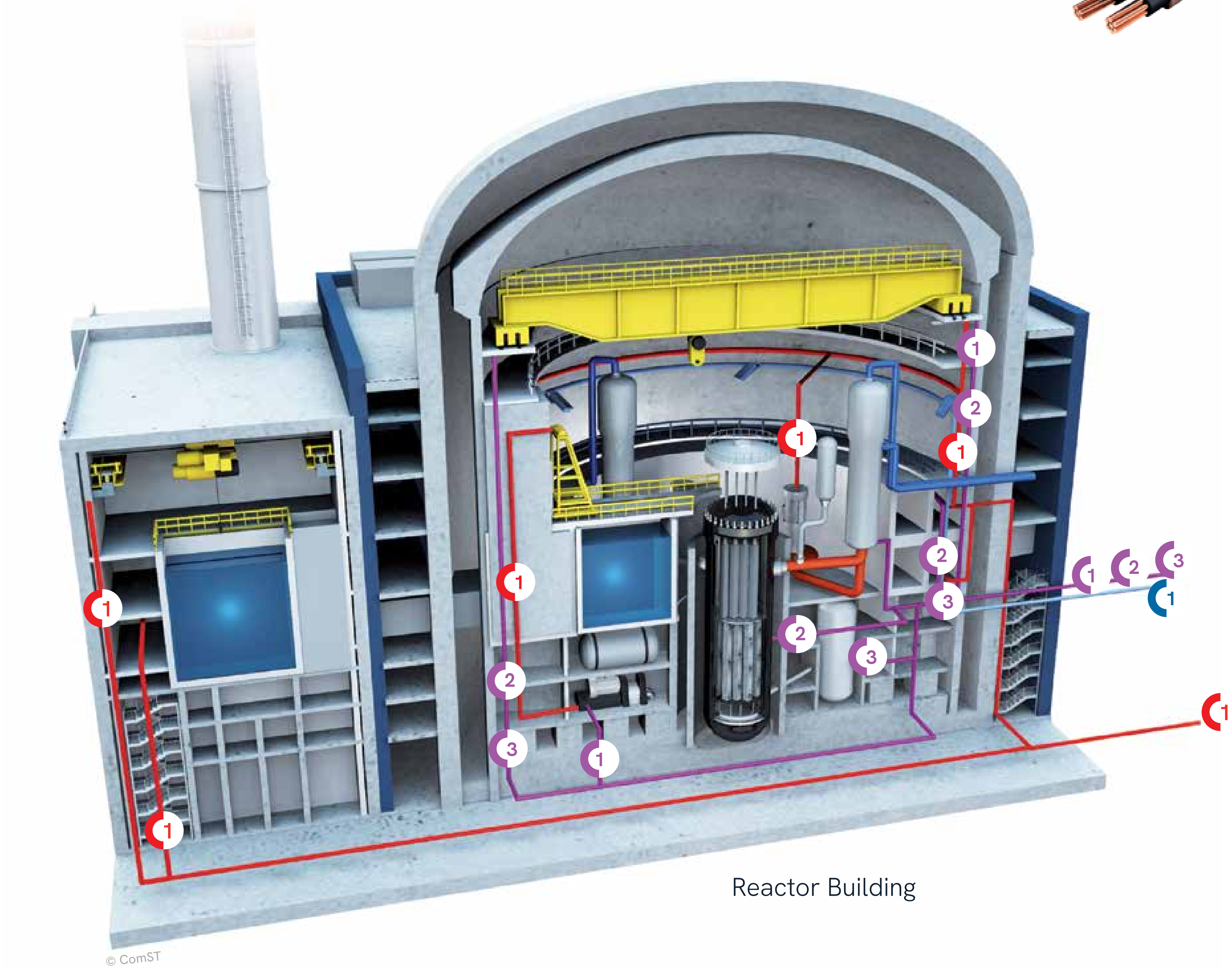
These LOCA tests are done in specially equipped autoclaves, allowing the application of prescribed scenarios to the cable samples. Lynxeo is equipped with its own autoclave, and is able to do the tests beyond the usual specified parameters to be ready for future customer needs (up to 250°C and 20 bars).





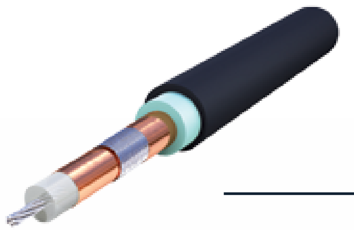
1E SAFETY Class

LOCA K1 & K2 Cables



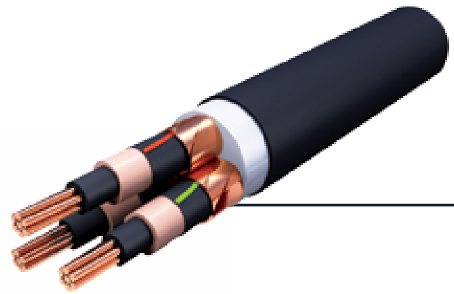
Reactor Building

Communication / Video networks



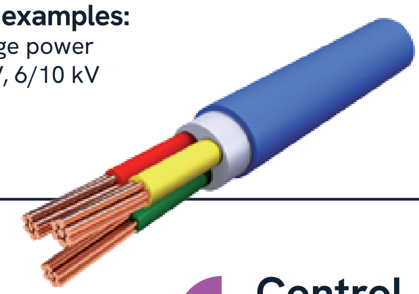
Application examples:
For some special applications (detectors...) and for video networks, coaxial or multi-coaxial cables.

Energy / Medium voltage networks



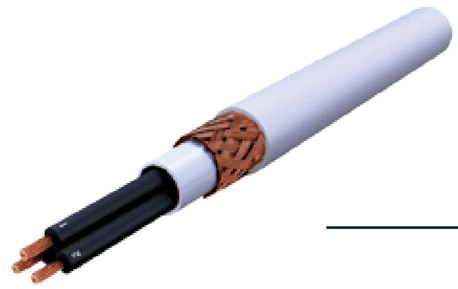
Application examples:
Medium voltage power supply (6/6 kV, 6/10 kV or 8.7/15 kV)

Energy / Low voltage circuits



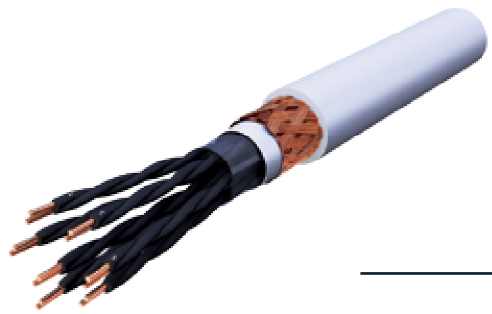
Application examples:
- Low voltage networks 0.6/1 kV
- Engine power supply
- Solenoid valve power supply

Control / Low voltage control circuits



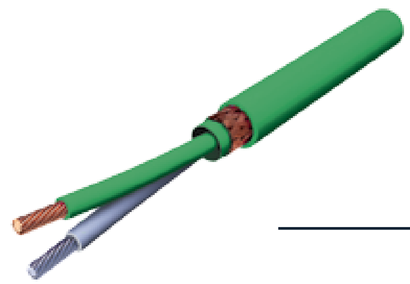
Application examples:
Connection to a variety of industrial equipment from control room. Many of them require anti-inductive screens (EMI).

Instrumentation / Measurement circuits



Application examples:
Connection to various types of measurement equipment with 300/500 V cables.
Can be multipairs, triads and quads. Generally, anti- inductive screen is required.

Compensation circuits

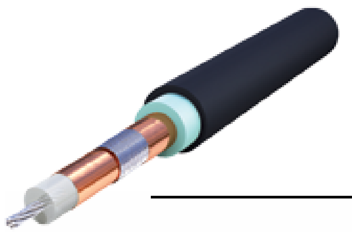


Application examples:
- Connection control board/ process for temperature measurement
- Thermocouple transmission signal

1E NON-SAFETY Class

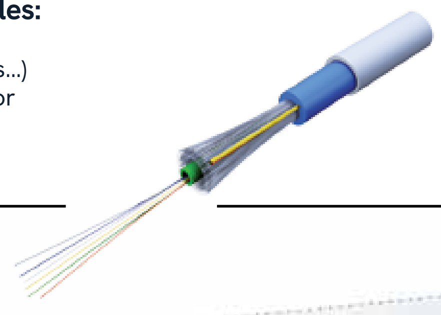
K3 Cables

Communication / Video networks

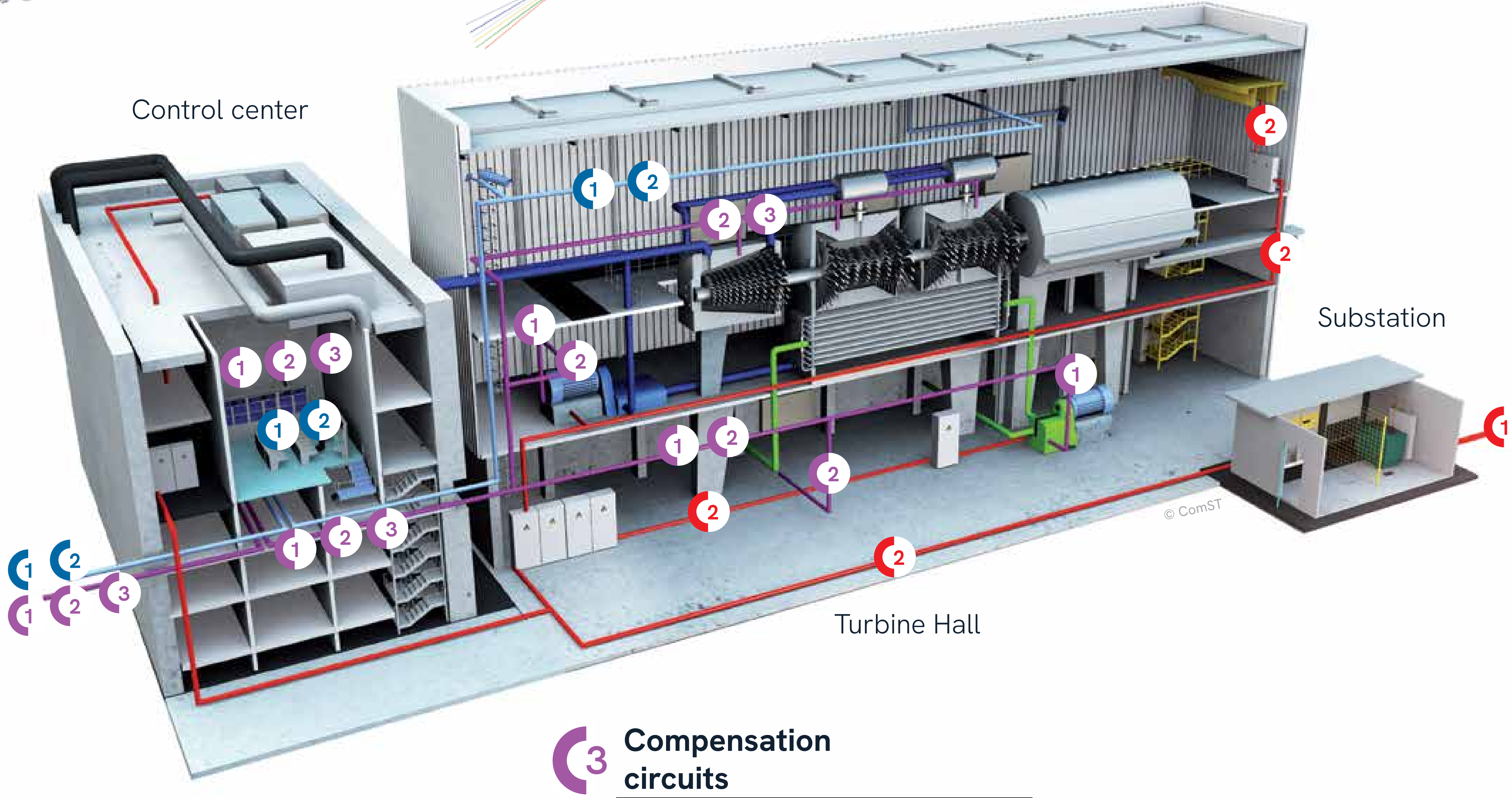


Application examples:
For some special applications (detectors...) and for video coaxial or multi-coaxial cables.

Communication / Data and video networks

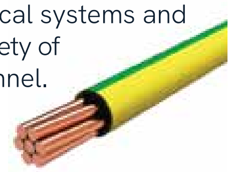


Application examples:
- Process zone data connection
- Video signal transmission

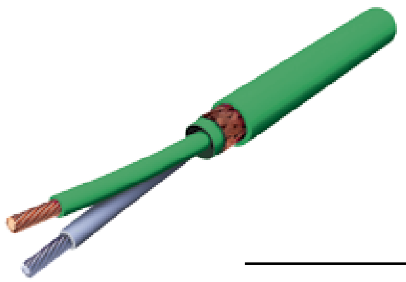


Earthing cables

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

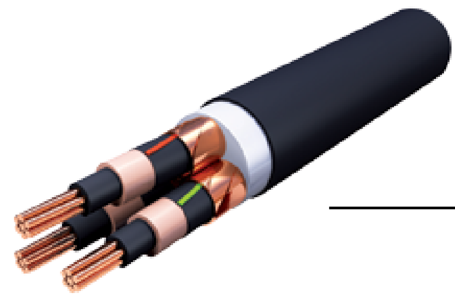


Compensation circuits



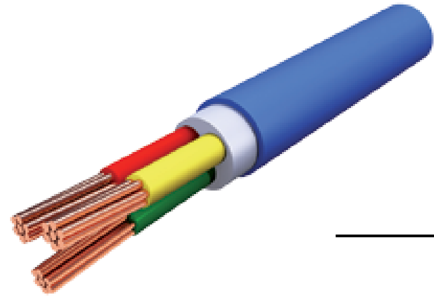
Application examples:
- Connection control board/ process for temperature measurement
- Thermocouple transmission signal

Energy / Medium voltage networks



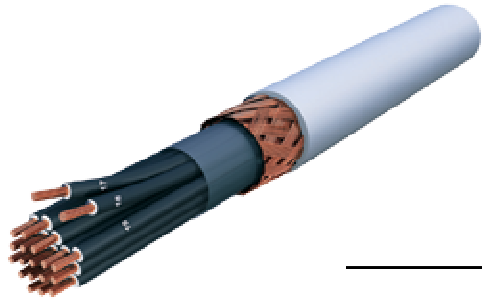
Application examples:
Medium voltage power supply (6/6 kV, 6/10 kV or 8.7/15 kV)

Energy / Low voltage circuits



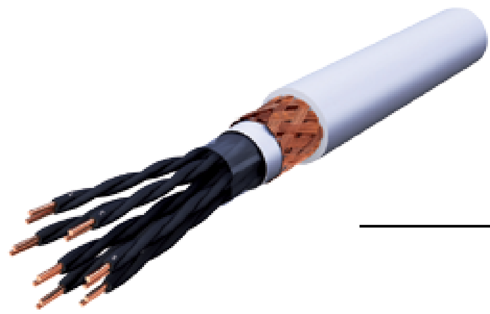
Application examples:
- Low voltage networks 0.6/1 kV
- Lighting system power supply
- Engine power supply
- Solenoid valve power supply

Control / Low voltage control circuits



Application examples:
Connection to a variety of industrial equipment from control room with 300/500 V cables.
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.

ENERGEN® nuclear cables

Solutions for nuclear island applications

Class 1E LOCA K1 & K2 Cables

Electrical equipment located inside the nuclear containment building plays an essential role in ensuring the safe and reliable operation of a nuclear power plant. The containment is the final barrier designed to prevent the release of radioactive material; as such, all equipment inside must be highly robust and meet the strictest safety requirements.

Within this challenging environment, electrical equipment is expected to function under elevated temperatures, high humidity, and substantial levels of radiation throughout the plant's operational life. In addition to normal conditions, this equipment must also remain operational during and after severe accidents, such as a Loss of Coolant Accident (LOCA), where sudden environmental changes occur within the containment.

Lynxeo cables classified under CST 74C068 are specifically designed and qualified for use in nuclear environments.

Product ranges

- Medium voltage energy cables
- Low voltage energy cables
- Control cables
- Instrumentation and sensor cables

Usage characteristics

- Designed acc. to CST 74C068
- **LOCA resistant for K1 ENERGEN® cables**
- **Radiation resistant for both K1 and K2 ENERGEN® cables**
- **Thermal endurance 60 years**
- Chemical resistant

Fire safety

- Halogen-free fire retardant
- Low smoke emission
- Low corrosivity and low toxicity
- Fire resistant Control and Instrument circuits acc. EN 50200 – IEC 60331-2 – or IEC 60331-1

Solutions for conventional island applications

Class 1E Non-Safety K3 Cables

The conventional island, also known as the non-nuclear or turbine island, encompasses all systems and buildings that are not directly involved in nuclear reactions. This area typically includes the turbine hall, generators, condensers, feedwater systems, auxiliary power supplies, and various support facilities required for plant operation. The conventional island is primarily exposed to industrial environmental conditions rather than nuclear hazards.

It is not necessary for cables installed inside the conventional island to demonstrate radiological resilience, as these areas are isolated from radioactive materials and exposure. However, every cable must demonstrate thermal resilience, given the potential for elevated temperatures associated with power generation and auxiliary machinery.

Product ranges

- Medium voltage energy cables
- Low voltage energy cables
- Control cables
- Instrumentation and sensor cables

Usage characteristics

- Designed acc. to CST 74C068.
- **Thermal endurance 60 years K3 ENERGEN® cables**
- Chemical resistant

Fire safety

- Halogen-free fire retardant
- Low smoke emission
- Low corrosivity and low toxicity
- Fire resistant Control and Instrument circuits acc. EN 50200 – IEC 60331-2 – or IEC 60331-1

Lynxeo ISO 19443 Certified Expertise

Nuclear safety is not limited to those who design technical components such as cables. It involves all players in the value chain, from engineers to operators, subcontractors and suppliers. Each link plays an essential role in guaranteeing a safe environment.

At Lynxeo, we have implemented a comprehensive set of rigorous measures to ensure that all our employees and partners fully understand their responsibilities. Our goal is to ensure that everyone involved in our operations – regardless of their function – is thoroughly aware of, and trained in, the safety requirements unique to the nuclear industry.

The ISO 19443 certification of our lead manufacturing factory is a reference framework that guarantees risk control and the continuous improvement of safety practices. This standard places particular emphasis on quality, traceability and safety culture, essential criteria for ensuring reliable performance at every stage in the lifecycle of nuclear infrastructures. Lynxeo is proud to comply with this standard, which reflects our commitment to excellence and safety. We strive to exceed these requirements, integrating continuous improvement processes that further enhance the reliability of our products and services in critical environments.

As a supplier of critical solutions to the nuclear industry, we are dedicated not only to delivering highly reliable ENERGEN® cables, but also to fostering a culture of safety that is embraced by all our teams and partners. True safety in nuclear energy is achieved not solely through advanced technology, but through collective responsibility and vigilance across our entire organization. By maintaining these standards, we play an active role in shaping a safer, more sustainable, and responsible energy future.

Notes

lynxeo

Wired to electrify industry

Industry is everywhere. Making our daily lives easier. Fostering progress. Moving the world. Industry plays a key role in shaping a better future.

We have been serving industry for generations. Today, we are committed to making it more efficient, more reliable and more sustainable.

Our cables are essential to the machines developed by global industry champions. They serve as the spinal cord of mission-critical infrastructures, assets and applications. Our clients rely on our advanced technologies and our industrial excellence to bring their machines to life.

In the century since we were founded, we have risen to a leading position in our markets.

Now, as a standalone company, we embark on a new journey with even greater agility, more focus and stronger customer intimacy.

For industry leaders, we are ever-evolving partners in an ever-changing world.

Together, we build connections beyond cables.

From energy transition to mobility and automation, our teams are tackling the greatest challenges of our times.

Our name is Lynxeo. We have local roots and global reach.

Connected to our customers, committed to excellence and progress, we are wired.

Wired to electrify the industries that move the world.

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