How to protect against concurrent and consequential hazards

Technical paper on sealing solutions for nuclear power projects

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Roxtec

Contents

About Roxtec

Roxtec is a global safety solution provider and value-adding partner serving and supporting customers with certified modular-based sealing solutions for cable, pipe, and conduit penetrations as well as technical expertise and sophisticated digital solutions for design, construction, and safe operations. Roxtec cable and pipe transits provide protection against multiple risks, including fire, gas, water ingress, electromagnetic interference, blast load and the risk of explosion, and make a difference in demanding industries and challenging projects worldwide. The sealing system contributes to ensuring safety, efficiency, and operational reliability. The Roxtec invention for adaptability, Multidiameter™, is based on sealing modules with removable rubber layers and ensures perfect tightness around cables and pipes of different sizes.

Headquartered in Sweden and with subsidiaries around the world, Roxtec is a group built on customer focus and an entrepreneurial spirit. The company's mindset is to help protect life and assets and make our world a safe and sustainable place. Roxtec has, for example, extensive research and development resources, a fire test lab and further testing capabilities for use in the product development and pre-certification process as well as for the customization of sealing solutions.

Referencing IAEA publications
Extracts from the following publications are reproduced with the acknowledged permission from the IAEA:
INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Nuclear Installations Against External Events Excluding Earthquakes, IAEA Safety Standards Series No. SSG-68, IAEA, Vienna (2021) (extracts from pages 4, 7, 16 and 42).
INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Internal Hazards in the Design of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-64, IAEA, Vienna (2021) (extracts from pages 18, 19, 23, 25, 27, 44, 46, 78 and 79).

Securing cable and pipe penetrations in line with IAEA safety guides

Nuclear power has the potential to provide a safe and sustainable source of energy when all safety protocols and regulations are followed. The importance of internal and external hazard protection in nuclear facilities, particularly in terms of barriers and separation, cannot be overstated. Protective measures are essential for ensuring the safety and integrity of nuclear power plants and small modular reactors, SMRs.

Nuclear facilities can face multiple hazards simultaneously. For example, an earthquake can be followed by extreme weather, fire, and flooding. Robust barriers and separation systems must address these challenges, be designed to prevent accidents, protect health and safety of the public, limit environmental impact, and ensure the long-term viability of nuclear energy.

This paper presents a way of securing cable and pipe penetrations in line with two IAEA Specific Safety Guides, SSG-64 and SSG-68. Our conclusion is a recommendation to standardize with Roxtec cable and pipe seals in separation barriers, walls, floors, and cabinets throughout any nuclear facility.

Nuclear power is considered a green and low-carbon energy source as it generates electricity with minimal greenhouse gas emissions. It is therefore a part of the efforts to combat climate change. Unlike fossil fuels, such as coal and natural gas, nuclear power does not release carbon dioxide (CO_2) during electricity production. Instead, it relies on controlled nuclear fission of uranium or other radioactive materials to generate heat, which is converted into electricity. This makes nuclear power an option for reducing greenhouse gas emissions and transitioning towards a sustainable energy mix.

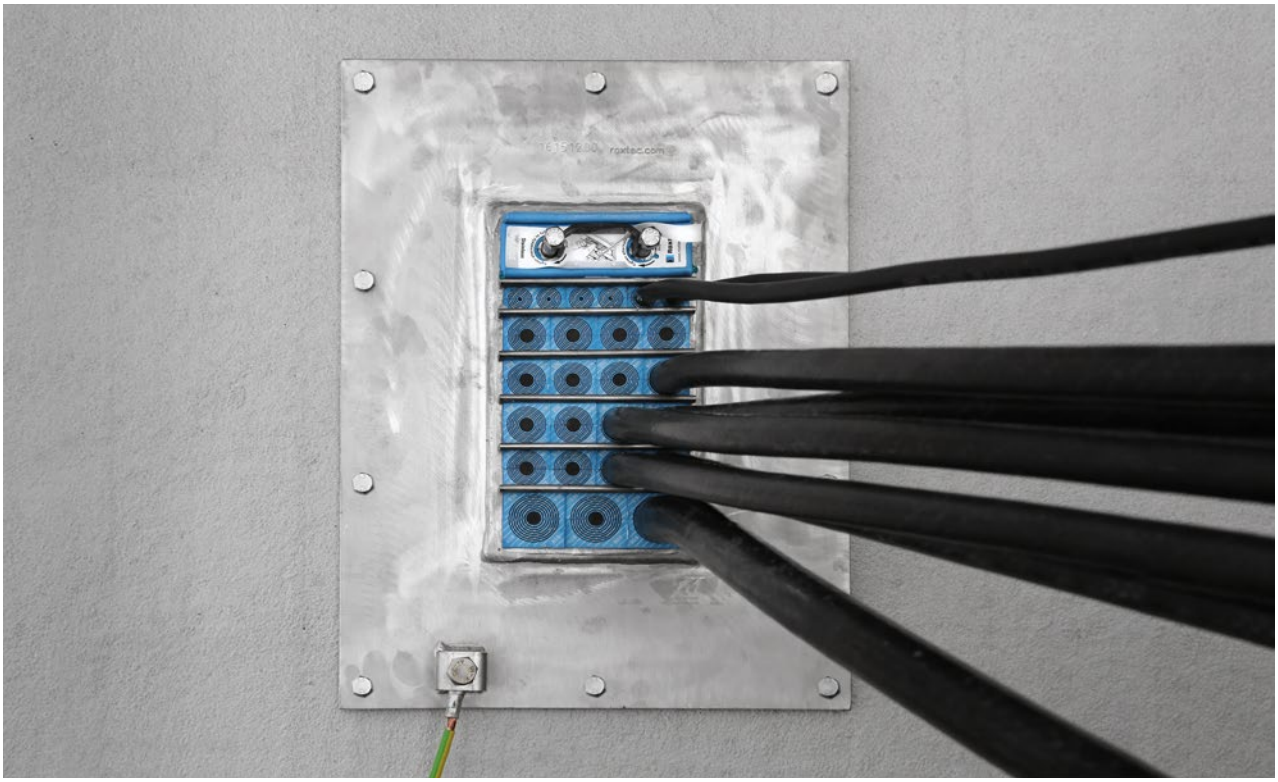
Measures to minimize risk

Numerous safety measures, stringent regulations, and advanced technologies must be in place to minimize the risks associated with nuclear energy. These measures include robust reactor designs, multiple safety layers, rigorous operator training, regular inspections, and emergency response plans.

The global nuclear industry continually strives to enhance safety through research and development.

This commitment to safety means continuous vigilance to prevent accidents, protect the environment, and safeguard the well-being of people, and the nuclear industry has a strong safety record. Accidents like Chernobyl and Fukushima have highlighted the risks, but they are exceptions. The industry has learned lessons from these accidents, leading to even greater emphasis on safety.

Multidisciplinary design approach



The process of designing and gaining regulatory approval for a nuclear facility involves an approach that integrates requirements, engineering design, safety considerations, and regulatory compliance. The consideration of internal and external hazards is paramount in the design of nuclear power plants and other nuclear facilities to minimize the risk of accidents. This calls for a multidisciplinary approach with input from engineers, safety experts, regulators, and others. Continuous updates and periodic safety reviews are essential to ensure that the facility remains resilient to evolving hazards throughout its operational life and to guarantee the safety of the staff, the public, and the environment.

Safety factors in design and operation

Redundancy, diversification, and separating barriers are crucial principles to enhance safety and mitigate the risks associated with nuclear power facilities and operations.

1. Redundancy
Redundancy involves having multiple, identical, or diverse safety systems or components that can perform the same safety functions. Redundancy ensures that if one system or component fails, there are backups to maintain safety. This principle is vital to prevent accidents and maintain control even in the face of equipment failures or human errors. It enhances reliability and fault tolerance, reducing the risk of accidents and consequences.

2. Diversification
Diversification is the practice of using different technologies, materials, or approaches in safety systems and processes. It minimizes the risk of failures where multiple components or systems fail due to a shared vulnerability (CCF, common cause failure). By diversifying safety measures, nuclear facilities reduce the risk of a single point of failure compromising safety. This practice adds layers of protection and resilience to the overall safety framework.

An example of safety diversification can be found in back-up power provision, emergency power provided by back-up diesel generators with secondary provision by battery back-up. If the generator sets are compromised, power can be drawn from a different type of back-up system to ensure safe operation in the event of a loss of power.

3. Barriers/separation

In the design of nuclear power plant safety systems, redundancy and diversification can only be maintained if hazards and their associated consequences are prevented from spreading to multiple systems, components, or structures.

This is accomplished by establishing and maintaining robust barriers and separation systems. All these protective measures against internal and external hazards, particularly in terms of barriers and separation, are essential for ensuring safety and integrity. These physical separation systems are designed to address, contain, withstand, and mitigate the impacts of multiple simultaneous challenges, such as earthquakes followed by flooding or extreme weather events. These protective measures prevent, slow down or limit the effects in the event of an accident. Barriers are critical for ensuring the safe operation of nuclear facilities in the face of multiple potential threats.

"The design of equipment shall take due account of the potential for common cause failures of items important to safety, to determine how the concepts of diversity, redundancy, physical separation and functional independence have to be applied to achieve the necessary reliability."

IAEA Specific Safety Requirement SSR-2/1 Rev 1 "Safety of nuclear power plants – design", requirement 24, reproduced in IAEA Safety Standards Series No. SSG-68 (see reference om page 3).

Design considerations – internal and external hazards

Defense in depth is a fundamental multi-layered safety principle applied in the design, operation, and regulatory oversight of nuclear power facilities. It involves the implementation of multiple, redundant, and independent layers of safety measures and systems to prevent accidents and protect against the release of radioactive materials. The goal is to ensure that even if one or more safety barriers fail due to unexpected events, there are reliable additional layers of protection to maintain safety.

Here are the key principles and layers of defense in depth within nuclear safety:

- Prevent the hazard
- Limit the severity of the hazard, should it occur
- Limit the consequence of the hazard, should it occur and be severe

Nuclear design, addressing both internal and external hazards, is a process that entails:

1. Internal hazard mitigation
Robust engineering, safety systems, and a strong safety culture prevent and respond to internal hazards like equipment failures and human errors.

2. External hazard resilience
Nuclear facilities are designed to withstand natural disasters, terrorist threats, and other hazards through structural integrity, redundancy, and comprehensive safety measures.

3. Safety barriers
Barriers, both physical and procedural, are integrated into the design to mitigate potential accidents, ensuring the protection of personnel, the public, and the environment.

4. Regulatory compliance
Adherence to strict regulatory standards ensures that nuclear designs meet safety requirements and mitigate internal and external threats.

"All foreseeable internal hazards and external hazards, including the potential for human induced events directly or indirectly to affect the safety of the nuclear power plant, shall be identified and their effects shall be evaluated. Hazards shall be considered in designing the layout of the plant and in determining the postulated initiating events and generated loadings for use in the design of relevant items important to safety for the plant."

IAEA Specific Safety Guide SSG-68 (see reference on page 3).

External hazards

External hazards are usually defined as events happening outside the primary plant. Section 1.13 of the IAEA SSG-68 describes a wide scope of "human induced" and "natural" events to be considered:

This Safety Guide is applicable to the design of new nuclear installations and the safety evaluation of existing nuclear installations in relation to the following external events:

Human induced events:

- Accidental aircraft crashes
- Explosions (i.e. deflagrations and detonations) with or without fire and with or without secondary missiles
- Release of corrosive or hazardous gases or liquids (e.g. asphyxiant, toxic) from off site or on site storage or during transport
- Release of radioactive material from off site sources or from the site
- Fire generated off the site or from on site sources
- Collision of ships or floating debris with safety related structures, such as water intakes or structures associated with the ultimate heat sink
- Collision of vehicles with SSCs (classification of structures, systems and components)
- Electromagnetic interference from off site or on site sources
- Floods resulting from the rupture of external pipes
- Any combination of the above resulting from a common initiating event, for example an explosion with fire and a release of hazardous gases and smoke

Natural events:

- Floods due to events such as tides; tsunamis; seiches; storm surges; wind generated waves; precipitation causing flooding of nearby rivers and streams; dam forming and dam failures; bores and mechanically induced waves; channel migration; and high groundwater levels
- Extreme meteorological conditions (of temperature, snow, hail, frost, subsurface freezing and drought)
- Extreme winds, including straight line winds, winds due to tropical storms (e.g. cyclones, hurricanes, typhoons) and tornadoes
- Dust and sandstorms
- Lightning
- Volcanism
- Biological phenomena

IAEA Specific Safety Guide SSG-68 (see reference on page 3).

The consideration of the external hazard range is a critical aspect of ensuring safety and resilience of nuclear facilities. Natural disasters and human-made threats can pose significant challenges to the safe operation of nuclear power plants. They are the test to which diversification, redundancy and the barriers that protect these functions are measured against for effectiveness.

Multi-hazard protection by Roxtec

Roxtec cable and pipe seals are passive protection systems that are designed to protect against multiple concurrent and consequential hazards, internal and external as well as human induced and natural. When studying several sections of SSG-64 and SSG-68, it becomes clear that the Roxtec sealing system provides the multi-hazard protection that is required within nuclear safety. These passive systems ensure the integrity and operability of the active safety systems they protect.

Protecting against water ingress

Service penetrations are highlighted in relation to flood mitigation in section 5.21 of SSG-68 Section C (iii) that states:

> The nuclear installation should be protected against the design basis flood by one or more of the following means of protection…
>
> IAEA Specific Safety Guide SSG-68 (see reference on page 3).

This is expressed more specifically in SSG-64 Section C (iii) on watertight doors and penetrations:

> 4.160. Cable trays should be designed in a manner that limits flood propagation. Examples of design features to do so include drainage holes and watertight penetrations.
>
> 4.161. To the extent practicable, watertight penetrations should be manufactured from material that is resistant to material degradation, and should be installed in locations that facilitate inspection and maintenance.
>
> IAEA Specific Safety Guide SSG-64 (see reference on page 3).

Responding to all requirements

Roxtec round and rectangular cable and pipe seals provide certified protection against humidity, water ingress and flooding. The transit frames are made from durable materials, such as stainless steel, aluminum or composite, and the EPDM rubber is developed to withstand ageing and heat. The seals are also appreciated for bringing order to high cable density areas, for being openable for late changes, easy maintenance, and future additions, and for simplifying visual safety inspections.

The SSG-64 also mentions specific flooding hazard considerations that should be made:

4.169. In addition to the direct impacts of flooding (e.g. spray, submergence) as described in this subsection, the release of water into a room might also have a significant effect on the general environmental conditions. Such effects (e.g. increase in humidity, radiation levels, temperature) should be considered in the qualification process for equipment. Special consideration should be given to potential releases of dissolved hydrogen in water and to fluids other than water (e.g. chemicals used for fire suppression).

4.170. The design should take into account that water present during an internal flood could impose a hydrostatic load on those SSCs in contact with the water (e.g. doors, walls, floors, penetrations). If not properly accounted for, this could lead to structural failures and damage from falling objects or heavy load drop. It could also lead to failure of barriers and doors important to safety.

IAEA Specific Safety Guide SSG-64 (see reference on page 3).

Eliminating the effects of humidity

Roxtec cable and pipe seals are often used to secure areas with sensitive equipment from the risk of humidity and temperature changes. The watertight seals make sure that the effects of humidity, such as PD, partial discharge activity, is avoided, and being air-tight, they contribute to a stable indoor climate. The seals enable airflow management and optimize conditions for air-conditioning or cooling systems. The seals are tested to withstand aggressive steam, toxic fumigants, and chemicals, and they are certified to be fully capable of resisting both constant and catastrophic water pressure.

Consult the white paper "Humidity effects in substations" by EA Technology for further information on how to avoid the risk of partial discharge activity by using watertight cable and pipe transits. It is available on roxtec.com.

Providing certified fire protection

SSG-64 and SSG-68 respectively emphasize the need for separating fire barriers:

4.33. The segregation of redundant parts of a safety system ensures that a fire affecting one division of a safety system would not prevent the execution of the safety function within another division. This should be achieved by locating each redundant division of a safety system in its own fire compartment or at least in its own fire cell. The number of penetrations between fire compartments of different redundant divisions should be minimized and the penetrations should be sealed in a qualified manner.

AEA Specific Safety Guide SSG-64 (see reference on page 3).

5.102. Protection of the installation against fires that originate outside the site should be achieved by minimizing the probability of an external fire and by providing protective measures against external fires, where necessary. Measures should be taken to reduce the amount of combustible material and inflammable material in the vicinity of the site and near access routes to the site; alternatively, adequate fire protection barriers should be installed. Vegetation that could propagate a fire in close proximity to the installation should be removed. Other design measures, such as the physical separation and redundancy of safety systems, separate fire compartments or other fire barriers, and fire detection and fire extinguishing systems (e.g. sprinkler systems), should also be provided as appropriate.

IAEA Specific Safety Guide SSG-68 (see reference on page 3).

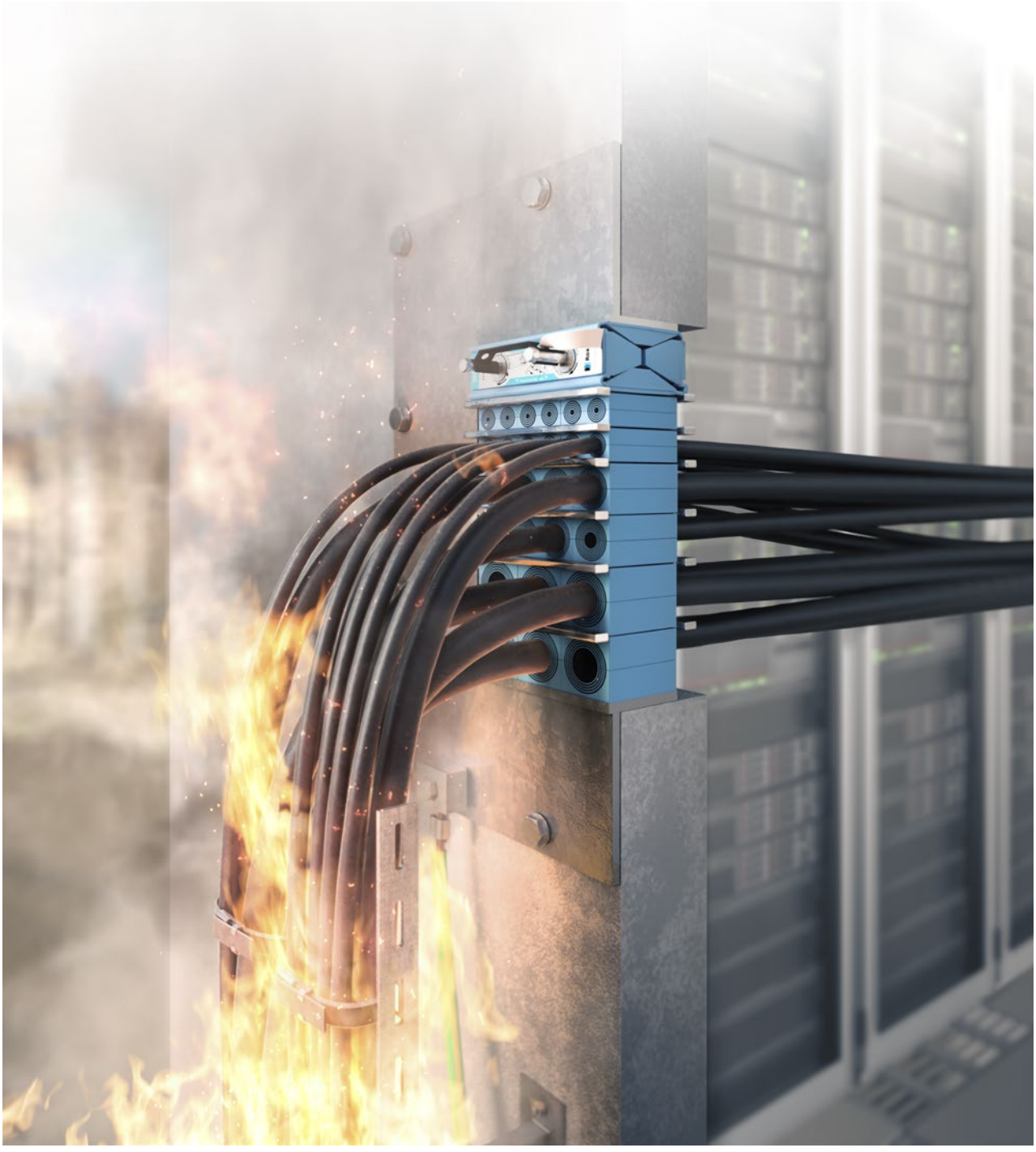
Fire rated seals securing barriers

Roxtec cable and pipe entry seals protect against smoke and fire. The fire-resistant system secures an efficient fire barrier, and it is tested and approved by certifying authorities all over the world. The Roxtec sealing system can be used for all types of penetrating electrical cables, steel pipes, plastic pipes and conduits passing through walls or floors or entering cabinets, enclosures, or equipment. Roxtec seals are "more than a firestop" and suited for sealing gaps and openings to prevent the spread of fire. Roxtec solutions have fire ratings ranging from E15 to EI240 or F and FT, and A0 to A60 or more. The seals are, for example, tested and approved according to EN 1366-3, UL 1479, and IMO 2010 FTP Code.

The seals are of high quality also when it comes to reaction to fire to make sure the materials do not contribute to flammability or combustibility. Roxtec seals with steel frames are tested with the SBI method and have the rating B-s1, d0 according to classification standard EN 13501-1. B represents "no flashover" and confirms the safest fire behavior possible for a combustible material.
Roxtec has an advanced fire test laboratory used for R&D, indicative and third party witnessed tests. All Roxtec type approval certificates are issued on basis of tests conducted at accredited independent test laboratories. Roxtec transits are approved for use in A class, B class, H class and J class fire rated sections. The system is jet-fire rated and approved according to ISO 22899-1:2021.

Fewer openings in barriers

Since the seals are area efficient and capable of handling very high cable density in a neat and orderly manner, they make it possible to reduce the number of openings needed in a fire barrier. The more cables that can pass through each penetration, the better the possibilities to ensure integrity.



Efficiently preventing gas leakage

Sections in SSG-64 underline the importance of gas-tightness:

4.32. The plant layout should be such that combustible materials (solids, liquids and gases) are not in proximity to items important to safety, as far as practicable. The design aim should be to segregate items important to safety from high fire loads and to segregate redundant safety systems from each other. The aim of this segregation is to reduce the risk of fires spreading, to minimize secondary effects and to prevent common cause failures.

4.51. In order to ensure their habitability, the main control room and the supplementary control room should be protected against the ingress of smoke and combustion gases and against other direct and indirect effects of fire and of the operation of extinguishing systems.

IAEA Specific Safety Guide SSG-64 (see reference on page 3).

Separating safety systems

Roxtec cable and pipe transits are gastight and enable full control of gas, steam, smoke, and particles. They respond to the need for preventing gas leakage and to requirements regarding separation of different combustible materials. Their main mission is to reinstate maximum integrity in any wall, floor, ceiling, cabinet, or equipment where there is a need for cable, pipe, and conduit penetrations. By keeping compartments safe and separated from each other, the seals protect redundant and diverse safety systems and contribute to long-term operational reliability for all parts of the safety diversification.

Preventing the risk of explosion

SSG-64 explains the importance of preventing explosion hazards in nuclear power facilities:

4.63. Flammable gases and liquids and combustible materials that could produce or contribute to explosive mixtures should be excluded from compartments (i.e. enclosed areas separated by barriers) that protect items important to safety against other internal hazards. Such flammable gases and liquids and combustible materials should also be excluded from areas adjacent to such compartments or areas connected to these compartments by ventilation systems. Wherever this is not practicable, quantities of such materials should be strictly limited, and adequate storage facilities should be provided. Reactive substances, oxidizers and combustible materials should be segregated from each other.

4.75. Some hazards (e.g. high energy arcing faults), while not formally explosions, are similar to explosions in terms of the loads they impart (e.g. temperature, pressure, missiles) on nearby SSCs; therefore, similar design provisions are appropriate for mitigating the effects of such hazards.

4.76. Design provisions to limit the consequences of an explosion (overpressure, missile generation or fire) should be in place. The consequent effects of postulated explosions on items important to safety should be assessed against the design objectives in para. 2.12. Access routes and escape routes for operating personnel performing manual actions important to safety should also be assessed and special design provisions should be implemented, if necessary.

IAEA Specific Safety Guide SSG-64 (see reference on page 3).

Blast-proof sealing solutions

The Roxtec cable sealing system is developed to prevent the risk of explosion through efficient separation of various substances as well as to withstand blast load and peak pressure. If there are requirements for Ex classification, Roxtec offers a range of Ex rated seals for use in hazardous areas.

Besides providing certified fire performance and appropriate IP and NEMA ratings for water ingress and dust, Roxtec seals add proven blast protection, reduce the risk of partial discharge failure on switchgear, and limit the effects of an arc-flash. The seals prevent typical conditions and causes of arc, such as relative humidity, dust, and vermin, and mitigate blast load or fire spreading in case of an arc-flash. The system is even tested and approved to help switchgear pass internal arc type tests.

Learn how to avoid switchgear failure by reading the white paper "Internal Arc & Arc-flash in HV/MV Switchgear" from Threepwood Consulting. It is available on roxtec.com.

Shielding against electromagnetic interference

SSG-64 contains several sections on electrical safety. It is crucial to ensure EMC, electromagnetic compatibility, while avoiding EMI, electromagnetic interference, and EMP, electromagnetic pulses.

4.188. Electromagnetic interference hazards can be categorized as internal hazards (e.g. caused by induction or radiation from installed equipment, either in normal operation or in fault) or as external hazards (e.g. lightning, radiation from solar flares, or radiation from equipment outside the site boundary and operated by other bodies).

4.189. In many cases, both prevention of the sources of electromagnetic interference and the ability of equipment to withstand electromagnetic interference are addressed by the standards for design and construction of equipment.

4.190. Electromagnetic interference should be limited such that the functioning of equipment is ensured. Recommendations on minimizing the effects of electromagnetic interference on instrumentation and control components or systems are provided in SSG 39 [6]. This includes a number of techniques, such as the following: (a) Suppression of electromagnetic noise at the source; (b) Separation and isolation of instrumentation and control signal cables from power cables; (c) Shielding of equipment and cables from external sources of magnetic and electromagnetic radiation; (d) Filtering of electromagnetic noise before it can couple to sensitive electronic circuits; (e) Neutralization or isolation of electronic equipment from ground potential differences; (f) Proper grounding of electrical and instrumentation and control equipment, raceways, cabinets, components and cable shields.

IAEA Specific Safety Guide SSG-64 (see reference on page 3).

Seals that protect against EMI and EMP

Roxtec provides sealing solutions for electromagnetic shielding as well as for bonding and grounding of armored and shielded cables. The Roxtec ES (electromagnetic shielding) sealing system ensures protection of sensitive electrical and electronic equipment from electromagnetic interference and electromagnetic pulses. The system covers the needs of demanding nuclear facilities and applications. Shielding is a method to reduce electromagnetic disturbances and block the field with barriers made of conductive or magnetic materials. It also works the other way round by preventing electromagnetic signals and electromagnetic fields from leaving a shielded area.

Extremely efficient bonding and grounding

The Roxtec BG™ system combines sealing, bonding, and grounding features in one transit. It provides an efficient low impedance connection to the cable armor, ideal for connecting conducted interferences to earth. Tests actually show a remarkable bonding efficiency level exceeding 99%.

When it comes to cabinet and enclosure applications, Roxtec BG™ multi-cable seals are much more area efficient than traditional cable glands. Certified to international safety standards, the seals help reducing installation time by 50 percent and enable users to save up to 70 percent space in their cabinets.

For wall and floor applications, where there is a need for preventing electrical disturbances from entering a building, Roxtec BG™ seals are quicker to use than methods that combine foam, clamps, and "pigtails".

Post-Fukushima learning on concurrent and consequential hazards

Despite many years of safe global nuclear operation, situations can occur that go beyond what had been considered or planned for. The accident at the Fukushima Daiichi Nuclear Power Plant on March 11, 2011, was a perfect storm of concurrent and consequential hazard occurrence with a sequence of events that compromised the safe shutdown of the plant. In the years following the accident, several amendments and improvements were made to guidance and governance of the industry, and recommendations from the IAEA were filtered down to national level by regulators around the world. In the UK, for example, the key learnings are summarized in the UK Office for Nuclear Regulation (ONR) update which outlines main considerations for safe design and operation:

"The potential for a hazard to affect safety should take account of the potentially widespread effects of external (and some internal) hazards (including concurrent and consequential hazards) which may challenge multiple safety functions and locations simultaneously. In addition, the hazard may affect multiple facilities, as well as the local and national infrastructure. Therefore, the impact on accident management and emergency preparedness arrangements, such as site access and services, and also consequential hazards from adjacent nuclear and non-nuclear facilities, should be considered."

SAFETY ASSESSMENT PRINCIPLES FOR NUCLEAR FACILITIES, Para 236, 2014 EDITION, REVISION 1 (JANUARY 2020), Office for Nuclear Regulation, UK.

The complete solution – protecting against multiple hazards

With Roxtec sealing solutions for cables and pipes, it is possible to ensure safety, efficiency, and operational reliability in traditional nuclear power plants as well as in new nuclear such as small modular reactors. Roxtec has the sealing expertise and a regulatory compliant technology as well as a full range of services, including technical support, customization, installation training, safety inspections, and digital tools for transit design and cable management. The seals prevent multiple risks and provide certified protection against concurrent and consequential hazards, which means they can maintain safety even when one event causes another and the threats accumulate. They can also limit the effect and severity of occurring external and internal hazards.

To secure safety in uncertain times, Roxtec seals are tested for everything from seismic events, effects of lightning strikes and electromagnetic interference to fire, gas, dust, pests, and flooding. They add blast protection, reduce the risk of partial discharge activity, and limit the effects of an arc-flash. They can also provide electromagnetic shielding as well as bonding and grounding.

Roxtec seals can be bolted, cast, or welded and used in walls, floors and cabinets or any other separation barrier. They provide immediate performance without any need for drying or curing and play a key role for securing equipment and back-up systems for full redundancy and diversification.

The seals are easy to use on a construction site or in an SMR factory for serial and modular production. Their great fill ratio lets users manage high cable density without compromising performance. Roxtec seals are easy to adapt to cables and pipes of different sizes and are openable to allow for changes. They provide spare capacity for additional cables and pipes to simplify project upgrades and expansion without the risk of interface or damage to already installed services.

They may be small modular components in a huge plant or a series of small modular reactors, but they add flexibility and scalability to nuclear power projects, and protection for all layers of conventional defense.

To summarize, Roxtec cable and pipe transits are highly recommended for nuclear power projects.

Protecting life and assets

Roxtec is the world leader within flexible cable and pipe transits. Since the start in Sweden in 1990, we have grown successfully to cover all continents. Our passion is innovative sealing solutions, and our goal is to make our world a safer place.

- Extensive R&D resources and advanced test facilities
- Inventor of Multidiameter™
- Customers in more than 80 markets

Would you like to learn more about cable and pipe seals for nuclear power projects?

Scan the QR code or visit roxtec.com

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