In March 1999, a truck carrying nothing but margarine and flour entered the Mont Blanc Tunnel, a vital 7½ mile trans-Alpine artery linking France and Italy, and triggered one of the deadliest tunnel fires in history. The conflagration burned for fifty-three hours and reached a temperature of 2,000°F in just ten minutes. It claimed the lives of 39 people and the loss of 37 vehicles, including 2 fire engines. Later research showed that heat output of the fire reached 300 MW. Three quarters of a mile of concrete lining were utterly destroyed and repairs took three years to complete.

Total losses including lost revenue came to US$200 million. The tunnel re-opened in May 2002 with no fireproofing.
The Channel Tunnel, one of the most celebrated engineering marvels of the modern world, was not fireproofed based on a risk analysis that showed the probability factor for major fires was once every 300 years. Two years after opening, a train caught fire and stopped half-way through the tunnel. The ensuing blaze incinerated nine carriages and caused severe damage to a half-mile stretch of the tunnel. Only 2” of the original 18”-thick concrete lining remained in some areas. Firemen complained of being “showered with burning concrete”. Fortunately no lives were lost, but engineers would later discover that, had the train stopped 800 yards further down the line, it is likely the tunnel would have collapsed. Total losses, including lost revenue during renovations, was estimated to be as high as US$300 million, ten times more than the initial cost of fireproofing.

The tunnel re-opened in May, 1997, again with no fireproofing.
DEVASTATING EFFECTS

Life is threatened
- Asphyxiation
- Poisoning
- High temperatures
- Spalling concrete may block escape routes and cause injury

Structure is threatened
- Major loss of concrete lining due to explosive spalling
- Weakening of concrete at temperatures above 400°F
- Weakening of steel reinforcement at temperatures above 480°F
- Damage to tunnel joints and seals, leading to water leakage and possible failure of an immersed tube construction

Infrastructure is threatened
- Prolonged closure
- Major traffic diversions
- Overloading of the local road infrastructure
- Environmental damage

Revenues are threatened
- Local businesses affected
- Transportation routes affected
- Repairs are costly
- Total costs can exceed $1.5 million per day
Fires in long tunnels are a rare occurrence, but when they do happen, they can burn for days on end, reach temperatures above 2,400°F and achieve heat outputs in excess of 300MW.

The severity of the Mont Blanc and Channel Tunnel fires, as well as other more recent fires in the Tauern and Størbelt tunnels, served as a wake-up call to transportation authorities and civil engineers around the world. Risk assessments undertaken prior to the construction of these tunnels failed to foresee the intensity of the fires that would eventually incapacitate them. The severe damage to structure, long closure periods, and loss of revenues had catastrophic consequences to these tunnels and to their surrounding environments.

We must consider the following important questions:

- Why are tunnel fires so severe?
- Why do concrete tunnel linings fail in fire?
- Is there any way to protect them from spalling?

Isolatek International has undertaken to answer these and other questions for the tunnel engineer and owner. As the world’s leading manufacturer of passive fire protection products for over 125 years, Isolatek International offers a full range of products and systems that protect structural components in office buildings, hospitals, oil refineries, and tunnels from fires of all intensities.

In this binder, Isolatek shall highlight its Tunnel Lining Fire Protection System, based on Type MII® high-density fire resistive material.
The company and its tunnel operations

Isolatek International has over 20 years of experience in passive fire protection for tunnel linings. Operating from a worldwide perspective as consultant, manufacturer and supplier of fire protective coatings, Isolatek International is able to contribute during every stage of a project from conception, specification and on site technical support through to its completion.

Isolatek International considers the fire protection requirements for tunnels by taking structural requirements, construction techniques, fire loadings and safety issues into account when preparing detailed technical specifications. Thorough understanding of cellulosic and hydrocarbon fires and their likely effect on a tunnel lining ensures that individual solutions are provided for all types of tunnels including:

- **Cut and cover**
- **Bored tube**
- **Immersed tube**

Application of a suitable coating at the required thickness will prevent concrete from spalling, and steel or cast iron linings from weakening under intense fire exposure.

Isolatek International's fire protection systems are supported by international, independent fire test approvals and assessments. In addition, in-house test facilities enable Isolatek International to carry out detailed fire testing on project specific designs and arrangements.

Fire in Tunnels – The Isolatek Solution

Isolatek International recognizes that road tunnel linings must meet prescriptive light reflectance requirements. They must also be resistant to regular jet washing or mechanical cleaning operations to remove surface contaminants such as rubber tire dust in order to prevent flash fires from occurring.

Isolatek International has developed an integrated system based on Type MII that meets all these requirements. Type MII is an inorganic coating based on exfoliated vermiculite and Portland cement which provides fire protection to the tunnel lining. Type MII will prevent concrete linings from spalling and structural steel elements from weakening during exposure to the intense heat generated in a tunnel fire.
The common approach to fireproofing tunnel linings has been to provide for added concrete over the structural requirements, in other words, to make the concrete linings thicker than needed. This approach assumes that the extra thickness of concrete, acting as a sacrificial layer, will delaminate in the event of a fire, thereby saving the structural component of the lining from being damaged and preventing tunnel collapse.

In theory. For instance, in the Channel Tunnel, 18-inch-thick concrete linings were used. The fire in 1996 lasted for only 9 hours, and yet afterwards only 2 inches of concrete lining remained. That equates to almost 2 inches of concrete lost per hour!

Fire brigades later reported that they were bombarded with burning concrete, that concrete rubble blocked escape routes, and that hot concrete on the ground burned through the soles of their protective boots.

**Channel Tunnel**

16" of concrete lost due to spalling

This dangerous and unpredictable phenomenon is known as **spalling**...
At normal temperatures, concrete has excellent compressive strength, and good resistance to heat. However, when exposed to temperatures above 400°F for long periods of time, it will begin to deteriorate. When temperatures increase rapidly (as in a tunnel fire) this deterioration becomes violent through a process called **spalling**.

**What happens**

Pressure inside the concrete rises as hydrated water turns into steam. Due to the dense structure of concrete, the steam cannot escape efficiently through its matrix. At the same time, the surface of the lining becomes weakened as it dehydrates. When the pressure within the concrete exceeds the strength of this surface layer, it will break away. Spalling will continue throughout the duration of the fire as each layer that delaminates exposes fresh concrete underneath to the intense heat.

Bored tunnels are the most susceptible to damage by spalling, as their lining segments are typically thinner and made of a higher strength concrete than those used in cut-and-cover and immersed-tube tunnels. High strength concrete is more dense and less porous than normal strength concrete, which means trapped steam will build up pressure at an even higher rate!

**Solutions for protecting tunnel linings**...

**Use of fibers in the concrete mix**...

**NO.** Polypropylene and steel reinforced fibers are not proven to alleviate spalling in concrete in high intensity fires, and repairs will be necessary to reinstate the lining after an incident.

**The installation of a sprinkler or deluge system**...

**NOT ENOUGH.** This type of protection requires a reliable water supply in order to extinguish or control the fire. In the Channel and Mont Blanc tunnel fires, these systems failed. Also, they do not protect the concrete structure during the early stages of a fire when spalling begins as a result of initial thermal shock.

**The use of a fire-protective coating**...

**YES!** A coating will slow down the rate of rise in temperature of the concrete to below 4°F/minute. By reducing the amount of heat flux to the lining, internal steam pressure is allowed more time to dissipate. Without a buildup of steam pressure, the spalling process is prevented and the concrete lining is preserved **intact!**
**Type MII** is a lightweight (44 pounds-per-cubic-foot) cementitious aggregate that is mixed with water and can either be spray-applied using a rotor-stator or mechanical piston pump, or troweled using normal plastering tools.

Portland cement acts as the binder, and the exfoliated vermiculite is the aggregate that provides the thermal performance and resistance to both hot and cold thermal shock from fire exposure and water impingement. Type MII is non-combustible and produces no smoke or toxic fumes during its exposure to fire.

Type MII was designed specifically to resist thermal shock associated with the rapid temperature rise of intense fires. It is for this reason that engineering firms such as Bechtel and Fluor have been specifying Type MII for decades to protect oil refineries from jet-fires and vapor cloud explosions.

Type MII works by slowing the rate of rise in temperature of concrete linings during intense fires with heat outputs as high as 350MW. By slowing the rate of heat to the concrete and its constituent steel reinforcement, Type MII will prevent concrete spalling both during the prescribed fire resistance period and beyond.

This action will prevent dangers such as blockage to exits, burning projectiles, and sudden collapse, increasing the fire brigades’ chances for success.

The figure above illustrates the behavior of some common construction materials when subjected to high temperatures. It compares their unprotected critical failure temperatures with those reached in the “standard” fire tests (see section on fire tests).
Until now, no statutory regulations existed for the passive fire protection of rail and roadway tunnels. But now progressive organizations like the National Fire Protection Association (NFPA), PIARC’s “World Road Congress”, and the European initiative UPTUN are acknowledging the benefits offered by passive fire protective coatings in tunnel linings, and are working on incorporating passive fire protection requirements into tunnel building regulations.

Until these regulations are implemented, tunnel owners, engineers and operators should take it upon themselves to recognize these benefits, and enhance the safety of their tunnels using passive fire protection.

A fire protective coating must satisfy the following requirements:

- The material and system must be fully tested to a relevant standard
- It must be easy to install
- It must be cost effective
- It should be non-combustible
- Light reflectance requirements must be satisfied
- Surface must be washable
- It must be resistant to salt spray attack, heavily sulphur laden atmospheres, acid gases such as C0₂, N0₂ and S0₂, smoke and detergent washes

**Type MII passes these requirements**
To ensure that constructions perform with some degree of predictability in a fire, “standard” fire tests are used to provide basic criteria against which the construction may be assessed. These standards require elements of construction to withstand a fire that follows a set Time/Temperature relationship. For tunnels and other industrial structures, the fire test “curve” simulates a free-burning hydrocarbon pool fire. Such “hydrocarbon” fire curves (e.g., UL-1709 and BS476 Part 20 App. D) are characterized by a rapid rise to 2,000°F in 5 minutes.

In the Netherlands, The Rijkswaterstaat and the Fire Research Establishment (TNO) refined the hydrocarbon Time/Temperature curve to represent the fire load of a burning 12,000-gallon petroleum tanker inside a tunnel. This fire test curve is commonly referred to as the “RWS” Standard and is characterized by a more rapid rise in temperature to 2,200°F within 10 minutes rising to a maximum temperature of 2,462°F at 60 minutes and falling back to 2,200°F after 120 minutes. The RWS fire test curve is considered to be the most onerous of all standard tests.

The chart to the right compares the fire curves for RWS (red), UL-1709 (green), and UL-263 (blue), a “cellulosic” fire standard used to test fireproofing for office buildings and other commercial structures. Notice that the cellulosic fire curve does not reach 2,000°F for 4 hours.

**Tunnel Fire Standard**

PIARC’S “worst-case scenario” for tunnel fires by the following two fire curves:

- **RWS** - 2 hr duration
- **UL-1709** - 4 hr duration

**Type MII has passed both fire tests**
Isolatek International has an unrivalled track record and experience in respect to the fire protection of tunnel structures, with major projects completed in the UK, USA, the Netherlands, Greece, Denmark, Hong Kong, China and Australia.

<table>
<thead>
<tr>
<th>Project</th>
<th>Country</th>
<th>Year</th>
<th>Client</th>
<th>Engineer</th>
<th>Contractor</th>
</tr>
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<tbody>
<tr>
<td>Hong Kong Mass Transit System</td>
<td>China</td>
<td>1980</td>
<td>MTR</td>
<td>Ove Arup</td>
<td>Univic</td>
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<td>Hyberg</td>
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<td>Holland</td>
<td>1996</td>
<td>DSM</td>
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<td>Willich</td>
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<td>Saturn</td>
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<tr>
<td>Limfjordtunnel</td>
<td>Denmark</td>
<td>1998-1999</td>
<td>Limfjord Region</td>
<td>Moonberg &amp; Thorsen</td>
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<tr>
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<td>Greece</td>
<td>1998</td>
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<td>OTC</td>
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<td>Perth City</td>
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<td>2001</td>
<td>Belgium Railway</td>
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<td>Trafalgar House</td>
<td>Structural Fireproofers</td>
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<td>USA</td>
<td>2001-2003</td>
<td>Mass. Turnpike Authority</td>
<td>Bechtel / Parsons</td>
<td>Island Lathing</td>
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<td>Westerschelde</td>
<td>Holland</td>
<td>2001-2002</td>
<td>RWS</td>
<td>KMW</td>
<td>Vogel</td>
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<tr>
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<td>France</td>
<td>2001</td>
<td>RET</td>
<td>KOOP</td>
<td>Vogel</td>
</tr>
</tbody>
</table>

**The Øresund Tunnel**

The Øresund Tunnel forms part of the fixed link between Zeeland in Denmark and Scania in Sweden. The 10 mile long tunnel, island and bridge link consists of a four lane motorway and a dual track high speed rail line between Kastrup near Copenhagen and Lernacken near Malmö. The 2.5 mile long immersed tunnel is constructed from 20 pre-cast concrete elements each weighing 55,000 tons which connect the artificial peninsula at Kastrup to the man made island in the Øresund. To protect the 1.9 million square feet of concrete from fire or explosion, they were spray coated with Type MII for an hourly rating of 2 hours.

**“The Big Dig”**

The largest and most technologically complex highway project in U.S. history is under the city of Boston. Called the Central Artery/Tunnel Project (but known to locals as “The Big Dig”) this massive undertaking was conceived of to replace Boston’s notoriously congested and antiquated elevated highway and tunnel system. When completed in 2004, 1.5 million square feet of the tunnel will be fireproofed with more than 160,000 bags of Type MII.
The Westerschelde Tunnel in Holland…

…the first tunnel in the world to be fire protected by a robot!

A typical 4-man crew can spray 150 bags of Type MII per day. This equates to about 1,250 square feet of tunnel lining per day at 1-3/4” thickness (for a 3-hour rating). This is more than adequate for jobs in the tens of thousands of square feet of surface area, but when the jobs get to be on the order of millions of square feet, it just isn’t enough.

You could hire more crews to get the job done quicker, or you can do what the Germans did in Holland: build a robot.

The Westerschelde Tunnel is a twin bored link between Ternauzen and Flushing in Holland. At 4.1 miles long, it carries 4 lanes of highway beneath the Schelde Estuary and contains 2.6 million square feet of concrete linings.

For the first time ever, application of Type MII was carried out by automated robotic spray equipment. Made by the Japanese and employed by a German contractor, the robotic sprayer allowed the full thickness of 1-3/4” to be applied in one continuous coat.

By comparison, the 4-man crew working with one spray machine would have to spray that thickness in 2, sometimes 3 coats.

Using recent advances in laser technologies to recognize the tunnel’s contours, the robotic sprayer, working full 24-hour shifts, sprayed between 3,000 and 4,000 bags per day of Type MII, completing the tunnel job in less than 8 months.
Vermiculite cements such as Type MII are porous and will absorb moisture when damp conditions exist inside a tunnel, releasing it again as the conditions change to a drier atmosphere. Acting as a condensation control system, vermiculite cements can prevent surface water from running down tunnel walls onto the road, which is especially good news for tunnels in colder climates where the water could ice up the road surface.

Vermiculite cements are also suitable for use in rail and metro tunnels and, when installed without a topcoat system, will satisfy sound absorption and fire protection requirements, providing noise reduction inside carriages of up to 9dB.
WASHDOWN CAPABILITY

If required for

- Light reflectance
- Surface illumination
- Routine washdown

It is common and practical to use epoxy-based coatings applied on Type MII surfaces. These coatings are odour free, waterbased products that provide...

- **Illumination**
  - High Light Reflective Topseal
  - A choice of colour

- **Washdown Capability**
  - Durable
  - High Impact Resistance
  - Topseal can take repeated high-pressure washes
  - Exceptional Chemical Resistance
  - Anti-static (dust does not adhere)
  - Reduces frequency of washdown
  - 25-year service life
  - Low Flame-Spread and Smoke Emission
Research, development and manufacturing

Isolatek International’s Research and Technical Centers in the USA and UK provide facilities for technical development that are essential to support its diverse activities and maintain its position as the world leader in fire protective coating systems. Manufacturing is based in the UK, USA, France and Italy, and through licensee manufacturing arrangements in Hong Kong, Korea, Singapore, Taiwan, Australia, India and Spain.

The diversity of Isolatek International’s operations

Isolatek International is the world’s largest supplier of passive fire protective coatings to the construction and hydrocarbon industries.

Tunnels
- 22 years experience in the fire protection of tunnel linings
- Over 10 million ft² of linings have been protected

Construction industry
- 30 years experience in the development, specification and supply of fire protective coatings for structural steel and concrete in multi-story buildings, hospitals, airports etc.
- Over 300 million ft² of building structures have been protected

Hydrocarbon industry
- Onshore petrochemical complexes
- 30 years experience in onshore petrochemical complexes throughout the world
- Over 40 million ft² of equipment structures, piperracks and storage vessels have been protected

Offshore installations
- 25 years experience on offshore installations throughout the world
- Over 30 million ft² of oil and gas production facilities have been protected

Quality assurance

Isolatek International’s operates a Quality Management system and is accredited to BS EN ISO 9002: 1994. Operating these systems is an assurance that all activities, from manufacturing, supply and technical support, follow written procedures to ensure constant quality control.

Warranty

Isolatek International offers project specific warranties during which time the fire protective coating is guaranteed to fully meet its performance requirements.