SOLIT Safety of Life in Tunnels

Engineering Guidance for a Comprehensive Evaluation of Tunnels with Fixed Fire Fighting Systems

using the example of water based Fixed Fire Fighting Systems

Scientific Final Report of the SOLIT² Research Project prepared by the SOLIT² Consortium

Annex 3
Engineering Guidance for Fixed Fire Fighting Systems in Tunnels

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This document was produced with best knowledge and with great care. These documents and its annex documents are for the use of experienced fire protection engineers. A case by case evaluation of the application of this document for a specific case must be done by the reader.

Classification:

The scientific research project SOLIT² - Safety of Life in Tunnels was promoted by the German ministry of economics and technology (BMWi; Code No. 19S9008) based on a decision of the German Bundestag. All members of the consortium have set up separate scientific reports related to their aim of study. Most outstanding outcomes have been concluded in the present Guidance. The Guideline has been set up jointly among the consortia members and presents the common final report. The Guideline is part of the work package. All individual reports are available on behalf of the project coordinator.

Imprint:

Engineering Guidance for a Comprehensive Evaluation of Tunnels with Fixed Fire Fighting Systems using the example of water based Fixed Fire Fighting Systems.

Annex 3: Engineering Guidance for Fixed Fire Fighting Systems in Tunnels

This document is based on the main document „Engineering Guidance for a Comprehensive Evaluation of Tunnels with Fixed Fire Fighting Systems". The following other annex documents are available:
Annex 1: Status analysis
Annex 2: Selected Results of Full Scale Fire Tests
Annex 4: Application Example for a Risk Analysis
Annex 5: Safety Evaluation of Technical Equipment
Annex 6: Life Cycle Costs of Technical Equipment
Annex 7: Fire Tests and Fire Scenarios for Evaluation of FFFS

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1. Introduction

1.1 Foreword

This document was prepared by the research consortium of the SOLIT² (Safety-of-Life-in-Tunnels) research programme. This is an Annex of the main document ***"Engineering Guidance for a Comprehensive Evaluation of Tunnels with Fixed Fire Fighting Systems"*** which focuses in particular FFFS as a compensatory measure for life safety and the protection of the infrastructure.

This document focuses on the technical design of FFFS in tunnels. It was developed on the basis of the *"UPTUN R251 Engineering Guidance for Water Based Fire Fighting Systems for Tunnels and Sub-Surface Facilities"*, produced as part of the European research project UPTUN (UPgrading methods for fire safety in existing TUNnels, www.uptun.net). Parts of this document *"Annex 3: Engineering Guidance for Fixed Fire Fighting Systems in Tunnels"* were derived directly from the UPTUN R251 Engineering Guidance document. Furthermore, results of the initial SOLIT research project carried out during 2004 and 2006 have been used as input for this guideline document. This document is produced exclusively for appropriately qualified and experienced people who understand tunnel safety systems and their interfaces, in particular for fire protection measures. It is not intended to replace national standards or codes that may demand higher engineering requirements than described herein. However, this document should be considered as a minimum standard for FFFS. Its content shall only be applied in the context of the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS".*

1.2 Purpose

The purpose of this document is to provide information on the minimum requirements for the design, installation and maintenance of FFFS in tunnels for the protection of users, fire services, equipment and the tunnel itself. This document does not comment on fire testing, but expects that all systems installed in tunnels will have passed suitable full scale type testing in controlled test conditions. It is the designer's responsibility to assess and develop the design of any FFFS in accordance with the parameters found to be effective in full scale fire tests. Authorities having jurisdiction shall examine any such design prior to its implementation. The design and installation shall in all cases comply with the relevant national standards.

1.3 Application and Scope

This engineering guidance document specifies requirements for FFFS for road and rail tunnels. In addition, this document may be applied to other, similar applications such as mine tunnels, underground stations and service or utility tunnels. It is the responsibility of the designers and authorities having jurisdiction to examine the suitability of this guidance for a specific application and whether any deviating or additional measures not being described herein should be applied.

This document does not cover any other fire fighting equipment in tunnels such as hydrants, wall cabinets and portable extinguishers.

1.4 Related documents

Relevant standards and codes shall be considered where appropriate. These include, but are not limited to:

2004/54/EC, Minimum safety requirements for tunnels in the Trans-European road network.

EN 54-4, Fire detection and fire alarm systems.

EN 12094-1, Components for gas extinguishing systems.

EN 12259-1, Components for sprinkler and water spray systems.

EN 12845, Automatic sprinkler systems – Design, installation and maintenance.

EN 1418, Approval of welding operators - Fusion and Resistance Welding.

prEN 14816, Water spray systems – Design and installation.

prEN/TS 14972, Water mist systems – Design and installation.

EN ISO 14847, Rotary positive displacement pumps – Technical requirements (ISO 14847:1999).

EN 15004-1 Gas extinguishing systems.

EN 50126: Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)

IEC 61508: Functional safety of electrical/electronic/programmable electronic safety-related systems (Parts 1-7)

97/23/EC, Pressure Equipment Directive.

2006/42/EC, Machinery Directive.

NFPA 13, Installation of Sprinkler Systems.

NFPA 20, Standard for the Installation of Stationary Fire Pumps for Fire Protection.

NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways.

NFPA 750, Standard on Water Mist Fire Protection Systems.

RABT, Richtlinie für die Ausstattung und den Betrieb von Straßentunneln, der Forschungsgesellschaft für Strassen- und Verkehrswesen, Issue 2006.

UPTUN R251, Engineering Guidance for Water Based Fire Fighting Systems for the Protection of Tunnels and Sub Surface Facilities – Report 251, UPTUN WP2.5, 2006.

1.5 Definitions

Additives — Chemical or mixture of chemicals intentionally introduced into the system e.g. for improving fire fighting performance or thermal resistance

AFFF — Aqueous Film Forming Foam

Area protection systems — Automatic or manually activated fixed fire fighting systems intended to fight a fire in the whole of a predetermined area rather than protecting only individual fire risks located in the area.

Authority Having Jurisdiction (AHJ) — An organisation, office or individual responsible for enforcing the requirements of a code or a standard or for approving equipment, materials, installation or a procedure.

Bus systems — A communication network built in tunnels

CFD — Computational fluid dynamics is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems that involve fluid flows and combustion.

Deluge system — Deluge systems are water-based FFFS, discharging water at low pressure in the form of a spray. Often referred to as sprinkler systems with open nozzles.

Design parameters — Parameters defining the detailed design of FFFS.

Design pressure — Minimum pressure at the nozzle as defined in full scale fire tests.

Fixed fire fighting systems (FFFS) — Systems being permanently installed in tunnels for fire fighting purposes and having automatic or semi-automatic operation via a remote control system. Examples include water mist, deluge and foam systems.

Foam systems — Fixed fire fighting systems applying a foam ratio over 4 as the fire fighting agent

Full scale fire test — Experimental fire tests organised in test facilities that are in similar scale with dimensions of tunnel as well as fire size.

Heat release rate (HRR) — The rate at which heat energy is generated by burning, expressed in BTU or megawatts (MW).

High-pressure water mist — Water mist system applying nozzle pressures above 35 bars.

Layout parameters — Parameters defining the general layout of a FFFS, e.g. distance between nozzles, maximum nozzle height, etc.

Length of tunnel — The distance from face of portal to face of portal measured using the centreline alignment along the tunnel roadway.

Low-pressure water mist — Water mist system applying nozzle pressures of less than 12 bars.

Maximum and minimum pressures — The maximum and the minimum working pressure of a component of the FFFS

Maximum pump pressure — Maximum pressure provided by the pump und normal working conditions.

Medium pressure water mist — Water mist system applying nozzle pressures between 12 and 35 bar.

Protection area — The total area covered when the maximum number of sections, that the pump system is able to supply at the design pressure, is activated.

RAMS analysis — A tool for studying and designing *Reliability, Availability, Maintainability and Safety* of FFFS and other safety systems in tunnel.

SCADA — Refers generally to tunnel control system and its user interface *(supervisory control and data acquisition)*

Section	An area covered by a set of nozzles, all of which are supplied through the same section valve.
Section valve	An automatic shut-off device which can be activated remotely and which separates the pipework of a section from the main supply pipe.
Shall	Indicates a mandatory requirement.
Should	Indicates a recommendation which is advised but not required.
Safety Integrity Level (SIL)	Defined as a relative level of risk-reduction provided by a safety function, or to specify a target level of risk reduction.
Water-based FFFS	A system permanently attached to the tunnel which is able to distribute a water-based extinguishing agent through all or part of the tunnel.
Water mist system	FFFS applying water as small droplets as the fire fighting agent. The mean diameter of sprays Dv0,90 measured in a plane 1 m from the nozzle at its minimum operating pressure is less than 1 mm

2. FFFS for Tunnels

2.1 General

FFFS installed in tunnels can be subdivided into various classes depending on the agent used and the function performed. The top level of classification is into water-based and non-water-based systems. Water-based systems can be further subdivided into deluge systems and water mist systems, both with and without the use of additives. Water mist systems may vary with respect to their working pressures; they are normally referred to as high and low pressure systems. Non-water-based-systems include so-called foam systems. All of these systems have been applied to tunnels, although water-based systems not using additives represent the vast majority of installed FFFS. Conventional deluge systems were mainly installed in the past, whereas water mist systems have become mainstream over the last decade.

2.1.1 System types

For detailed explanations of FFFS types and their specific working principles refer to Chapter 2.4.1 of the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS*".

2.1.2 The Effects of FFFS in Tunnels

For the detailed effects of FFFS in tunnels as well as the mitigation of effects on tunnel users, rescue services and the infrastructure please refer to Chapter 2.4.2 and 2.4.3 of the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS*".

FFFS for tunnels are not designed mainly to extinguish fires but to suppress or control them. All FFFS – deluge systems, water mist systems and foam systems - are limited in their ability to fight fires inside or underneath vehicles. It is to be expected that fire in such obstructed locations will continue to burn after activation of the FFFS. The main purpose of FFFS is thus to mitigate the impact of a fire. Even after activation, tunnel users and emergency personnel should anticipate fire in the tunnel when escaping from or approaching the area of risk respectively.

2.1.3 Exclusion / Warning

This guidance gives no recommendations for the use of glass bulb activated fixed water based systems in which sprinklers, spray heads or other components are activated or controlled individually by thermal elements such as glass bulbs. Considering the fire risk present in tunnels and the rapid development of fires and hot smoke as expected, the aforesaid systems shall not be used in tunnels. Fire tests have proven that individually activated sprinklers / spray heads do not provide the obligatory level of protection and are very sensitive for the effects of ventilation.

To ensure fast, effective and efficient fire suppression, a group of nozzles forming a section shall be activated simultaneously in the area upstream and downstream of the fire.

Subsequently, systems utilising glass bulb activated nozzles or combining such with open nozzles are considered unreliable for the protection in tunnels.

Furthermore it can be expected, that due to the harsh environment and possible mechanical damages by e.g. antennas the integrity of glass bulbs cannot be ensured. Considering the long life time of a system, safe activation may not be guaranteed.

The main document as well as the present annex 3 deal mainly with deluge and water mist systems; furthermore – as far the consortium had information and findings on – foam systems were considered. A summary of the findings of the SOLIT ² research project and interpretations of the research consortium to foam systems can be found in Sections 2.4.1 and 3.6 of the main document.

Statements regarding compressed air foam FFFS are neither made in the main document nor in this Appendix 3 because the members of the research consortium had an insufficient information basis on this topic. This restriction does not apply to FFFS where an additive in the form of a film-forming agent is admixed to the water and having an expansion ratio of less than 4.

3. System design

3.1 General arrangement of FFFS

FFFS described in this guideline are designed as so called "area protection systems". Nozzles are normally installed under the ceiling and/or at the upper part of the side walls, pointing downwards or at the centre of the tunnel.

In case of activation the fire fighting medium is dispersed into the protected area via these nozzles.

The whole protected area is covered with nozzles which are grouped into sections.

The sizing of section lengths shall be based on an analysis taking into account the fire test data.

All sections are connected by section valves and a main water supply line to the pump unit.

In case of activation of the FFFS (automatically by detection system or manually), at least one section valve will be opened accordingly and at least one pump unit will be started.

The pump system will provide water at the minimum pressure at least simultaneously for the defined minimum number of sections (normally two or three).

3.2 Basic design requirements

The design of a FFFS shall in all cases be based on:

- state of the art engineering methods,
- the methods defined in the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS* "
- design parameters of the specific FFFS.

As part of the design process for an FFFS for a specific tunnel the following aspects shall be considered as a minimum. The main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS"* describes general methods for the choice of system:

- potential fire risk
- level of protection
- other safety measures in the tunnel
- tunnel geometry
- ventilation/wind conditions during a fire, including interaction with emergency ventilation
- type and performance of the fire detection systems
- activation mode of the FFFS
- any restrictions in positioning and fixing the pipework or nozzles
- distance to emergency exits
- signage and lightning
- thermal conditions in the tunnel and its surrounding
- any specific requirements for the operation of the tunnel

3.3 Design parameters and fire testing

All major design parameters of any FFFS shall be derived from full scale fire testing. Such tests shall be performed in dedicated test tunnels suitable for such testing. The parameters of the tested FFFS and the test tunnel with its ventilation etc. determine the limits of the use of a specific FFFS in a tunnel, unless scaling of the results is specifically approved or otherwise acceptable to the authorities having jurisdiction.

Design parameters derived from fire testing shall include at least the following:

- nozzle types and makes with respective K – factors
- range of working pressures (min and max pressure)
- nozzle positions (distances to walls, ceiling, angles, orientation, etc.)
- distance between nozzles (longitudinal and transversal)
- min. and max. height of installation of nozzles
- min. and max. ventilation conditions
- maximum fire size at time of activation
- time to full operation after activation
- min. and max. section lengths
- min. and max. number of sections activated simultaneously

NOTE: A specific type (make) of FFFS does not require to undergo fire testing for each individual tunnel it may be installed in, as long as the major design parameters of the actual tunnel to be protected are within the parameters of the tunnel used for fire testing. CFD modelling shall not however replace full scale fire testing.

For further information on requirements for fire testing see Chapter 3.6.2 of the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS"* and related Annex 7. *"Fire Tests and Fire Scenarios for Evaluation of FFFS"*.

3.4 Mechanical design

3.4.1 Tunnel environment and materials

Equipment in tunnels shall be designed for a long life time, since a tunnel environment is normally very demanding on equipment and materials. Salt on the roads, high air humidity, locations close to the sea, vehicle exhaust pollution, particles from brakes or catenary, dirt and dust are typical aspects that require special consideration with respect to corrosion. At the same time, the highest possible reliability and availability for a FFFS are of paramount importance. Important components such as pipes, section valves etc. which are being exposed to the tunnel environment or in contact with water shall therefore be of high grade stainless steel to AISI316 or higher. A corrosion resistant coating shall not be used on such components.

For details see for example ZTV-ING, Zusätzliche Technische Vertragsbedingungen und Richtlinien für Ingenieurbauten, Teil 5 Tunnelbau or other appropriate guidelines for the specific country as well as the UPTUN R251 Engineering Guidance for Water Based Fire Fighting Systems for the Protection of Tunnels and Subsurface Facilities.

If additives such as foam concentrates, anti-freeze agents or microbial control agents are used, all components coming into contact with such additives shall have adequate corrosion resistance.

All materials used shall be in accordance with the requirements of the FFFS manufacturer.

3.4.2 Location of components

All components shall be installed in locations safe from damage by vehicles, e.g. in the event of an accident. Any components located in areas which can be reached by vehicles shall be protected by niches or solid mechanical protection capable of withstanding impacts from colliding vehicles. Special attention shall be paid to the main pipework and section valves.

3.4.3 Thermal effects and temperature rating

Thermal effects shall be taken into account in the design of all mechanical components. Depending on the location in the tunnel and climate conditions, thermal conditions may vary significantly. All components, especially pipework, shall be designed for operation throughout the range of expected temperatures. Temperature ratings of all components shall be suitable for the operating temperatures during standby and operation.

The normal operating temperatures shall be defined as the expected minimum and maximum temperatures outside the tunnel during standby. These temperatures shall be applied to the whole tunnel if the tunnel length is less than 1 km. In the case of tunnels longer than 1 km, an assessment may be carried out to determine whether the minimum operating temperature requirement may be adopted for the inner sections of the tunnel. For components installed in emergency exits or service galleries different operating temperatures may be acceptable, provided these areas are heated or insulated. If a minimum temperature of less than 0 °C is expected, the use of anti-freeze additives or heating devices shall be considered.

In the event of fire, temperatures affecting the FFFS rise rapidly. Pipework which full of water during standby is protected by a limited cooling effect before activation. All pipework will be provided with cooling after activation. For FFFS with no activation delay the effects of thermal expansion on pipework which is empty before activation shall be calculated applying sound engineering method using a design temperature of at least 250°C or as appropriate. For all water-filled pipework climatic temperatures shall be applied.

For FFFS with delayed activation required by authorities having jurisdiction, all FFFS components, whether the pipework is empty or filled with water during standby shall be capable of withstanding the anticipated temperatures before system activation. The same should apply to other safety components and systems in the tunnel.

3.4.4 Design lifetimes

The design lifetimes of mechanical components shall be defined on a project by project basis. The design lifetime shall generally be a minimum of 20 years for FFFS or as otherwise required by the authorities having jurisdiction. This applies to all components and materials being used.

3.5 Electric design

The design of all electric equipment shall be based on relevant guidelines for such equipment for use in tunnels, taking into account the high requirements for availability and reliability of FFFS. Special attention shall be given to the operating temperatures and environmental conditions.

3.6 Hydraulic design

3.6.1 Pump system capacity and redundancy

The pump system capacity shall be adequate to provide water and, where applicable, additives simultaneously for at least the defined minimum number of sections (normally two or three) at the minimum nozzle pressure at any location in the protected area.

The pump system redundancy shall meet the specifications and support RAMS calculations. Minimum one redundant pump shall be included.

3.6.2 Pressure loss calculations

Pressure loss calculations shall be carried out to ensure that at least the minimum nozzle pressure will be achieved at all nozzles in all possible hydraulic situations. The applicable minimum nozzle pressure for all nozzles shall be the pressure as tested in the full scale fire tests.

In systems using additives, the temperature of the fire fighting agent shall be taken into account for the determination of viscosity, depending on the minimum temperature in the tunnel.

The following standards should be taken into account as general reference when hydraulic calculations are carried out for the FFFS components:

- CEN/TS 14972
- NFPA 750
- EN 12845

3.6.3 Water hammer effect

The impact of water hammer shall be taken into account in the design of FFFS. Water hammer typically occurs in FFFS when section valves are closed too fast or empty pipes are filled (system deactivation or changing activated sections). Water hammer creates a pressure surge that can be critical especially for low-pressure systems and their components. Thus all section valves shall be designed in such a way that this phenomenon is avoided.

Water hammer occurs only if valves are closed faster than critical valve closing time, which is the time it takes for the pressure wave to travel through the pipework. When defining critical closing time t_c, a safety factor of 2 should be applied. The calculation for the critical closing time is as follows:

$$t_c = 200\% \cdot \frac{2 \cdot L_{pipe}}{\sqrt{\frac{B_w}{\rho}}}$$

L_{pipe} = Length of pipe between valve and pump station [m]

B_w = Bulk modulus of agent (water 20°: $2.1 \cdot 10^9 N/m^2$) [N/m^2]

ρ = density (water 20 °C: 998 kg/m^3)[kg/m^3]

For example a 1000 m tunnel requires valves that take at least 2,75 seconds to close in order to prevent water hammer when water is the pressure medium. Critical closing times for valves as a function of tunnel length are collected in the following figure 1 (pure water at 20 °C).

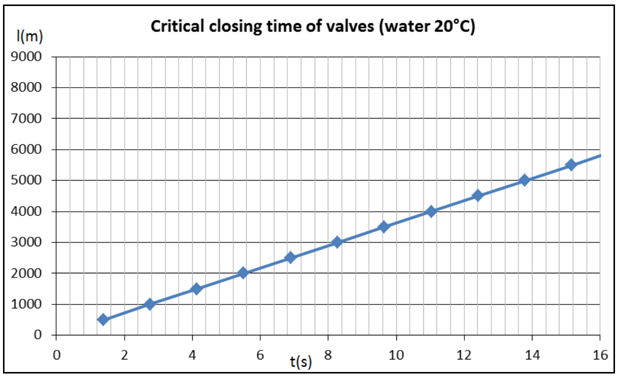

Figure 1: Critical closing time of section valves as function of tunnel length

3.6.4 Water quality and temperature

Water quality requirements of FFFS shall be specified by the manufacturer. Normally water-based systems use either potable water or water used by other fire fighting systems in the tunnel. Sea water may also be used during activation. If sea water is used, the system shall be thoroughly flushed with fresh water after activation.

Additives may be used for reasons such as protection against freezing, preventing tank deterioration or limiting microbiological growth. If such additives are considered to be a health hazard, safety data sheets shall be provided for the authorities having jurisdiction. Water quality shall be tested once a year or more frequently when appropriate.

Additives should be analysed at least twice a year. If water and additives are in standby as a premix solution in pipes, it must be ensured that they will not separate into two phases. Continuous rotation of the agents through the pipes shall be considered in order to avoid this.

The agent temperature shall not exceed 54 °C in the pipework or tank during stand-by.

3.6.5 *Flushing, pressure and leakage testing*

Flushing of the pipework shall be planned and carried out according to the manufacturer's documented requirements. Pipes should be protected with plugs during installation to prevent the access of foreign material.

Pressure testing shall be carried out in accordance with relevant standards at 1,5 times the design pressure. Pressure and leakage testing shall be witnessed by authorities having jurisdiction or their representatives. Documentation of pressure/leakage testing shall be supplied at the time of commissioning.

3.7 Design of the control system

FFFS may be operated in different ways depending on the risks protected, system type, control systems used and applicable standards and legislation. The main principles are explained on the thematic level in this chapter.

The control system of the FFFS should at least match the requirements regarding reliability and availability as defined for the control system of the emergency ventilation. It is recommended to implement all control systems for safety-critical systems in a tunnel with a SIL of 2

3.7.1 *Structure of the control system*

The control system typically consists of three parts: The main control system, the communication network and sub-control systems as shown below in the simplified figure 2.

3.7.2 *Overall control system*

The control system of the FFFS may be integrated into the tunnel's overall control system or be a separate system connected to it. Both systems are often located in the tunnel control room.

The overall control system shall include a user interface (e.g. SCADA), that is available for the tunnel operator in the tunnel control room, and where applicable, for the fire services at dedicated locations. The user interface shall provide information on the status of the main components such as the water tanks, pump station and section valves.

The overall control system shall normally incorporate redundancy if so required by the authorities having jurisdiction or RAMS studies show this.

3.7.3 *Communication network*

The communication network is normally part of the BUS system installed throughout the tunnel and the control room. The network shall incorporate redundancy for the case of cable breakage.

3.7.4 *Sub control*

Sub-control systems shall be installed in protected spaces such as emergency passages, fire points, technical rooms, etc.

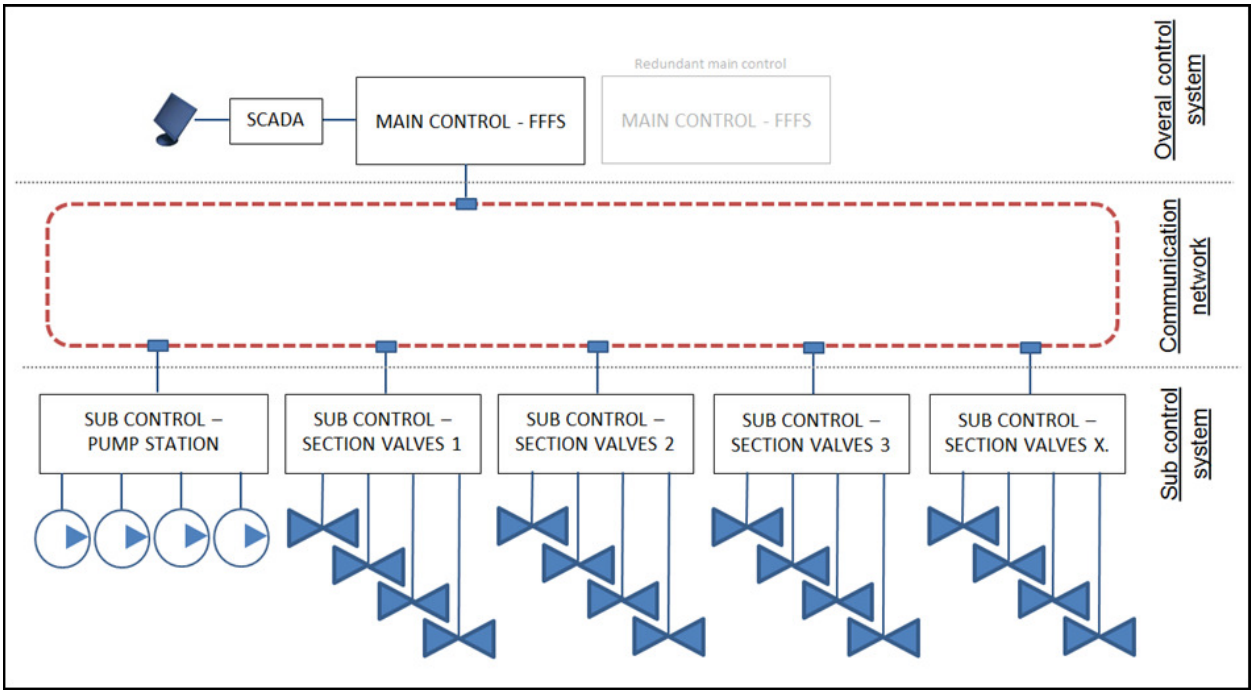

Figure 2: Typical structure of FFFS control system

The purpose of sub-control systems is to connect specific parts of the FFFS such as section valves or pump stations to the main control system. In addition, sub-control systems may provide functions required locally, such as status monitoring or service and maintenance functions for pump units, valves, etc.

3.8 Other design aspects

3.8.1 Drainage

Tunnel drainage systems shall be dimensioned to be able to evacuate the maximum flow rate of the FFFS in addition to standard requirements. If FFFS use additives, consideration shall be given to their collection and disposal.

Pump stations shall have a drainage capacity equal to the maximum flow rate of the water supply.

3.8.2 Fire detection and localisation

A detection and localisation system shall be foreseen to provide the necessary signals to activate the FFFS within the required time and at the right location.

The detection systems shall be able to detect and localise a test fire of 5 MW within 60 seconds (e.g. as defined in the RABT or other appropriate guidelines) with an accuracy as defined in Chapter *6.3. Operation and deactivation.*

It is recommended to use a more sensitive setting of the detection system to create a pre-alarm.

3.8.3 Time to operation

The full design flow rate shall be delivered from nozzles within 90 seconds of the activation signal.

In systems in which the fire fighting agent may constitute a health hazard, an additional delay shall be considered in order to avoid the risk of people being exposed to the fire fighting agent. The additional delay for evacuation of people shall be defined by the authorities having jurisdiction. Basically a delayed activation should be avoided since the FFFS should be activated as early as possible.

3.8.4 Ventilation

The ventilation system shall operate during operation of the FFFS as tested during the type fire testing.

3.8.5 Electric power supply

The power supply shall meet applicable national standards and legislation. Power supplies for FFFS shall have as a minimum the same level of reliability as required for the ventilation and main control system. If the power supply does not meet these reliability requirements, diesel generators or battery back-ups shall be provided. Alternatively, diesel engine driven pumps may be used.

3.8.6 RAMS (Reliability, Availability, Maintenance and Safety)

For the possible carrying out of RAMS studies as part of the design process of the FFFS see Chapter 3.7 of the main document "*Engineering Guidance for a Comprehensive Evaluation of Tunnels with FFFS*".

4. Components

4.1 General

Only components suitable for tunnel environments shall be used for FFFS. This refers especially to the materials used, maintainability, durability, etc. Owing to the special character of this application, there are no internationally accepted component tests for FFFS.

The examination of individual cases and appropriate test procedures used for other tunnel systems or FFFS in other application fields shall ensure the suitability of the components to be used.

4.2 Nozzles and other discharge devices

Nozzles and other discharge devices are components that spray or distribute the fire fighting agent into the protected areas. Examples of such are deluge nozzles ("sprinkler spray heads"), water mist nozzles and other discharge devices (collectively referred to as "nozzles" in the following).

4.2.1 Installation

The installation of nozzles shall comply with the manufacturer's documented requirements in accordance with type testing fire tests. They shall be installed under the soffit or at the upper part of the tunnel walls, protected from traffic to avoid damage by vehicles as a result of accidents. Nozzles shall be arranged such that vehicles will not reduce their efficiency by blocking the spray to a critical extent. This applies especially to systems having nozzles installed on walls or with just one row of nozzles along the tunnel ceiling.

Jet fans, lights, signalling and other possible obstructions shall be taken into account when installing nozzles. This may lead to local variations of nozzle spacing or lowering the installation position of nozzles, for example below jet fans. Variations in tunnel geometry, e.g. emergency stop lanes or other areas where vehicles potentially can enter, shall also be taken into account.

Nozzles should cover the entire tunnel length starting 10 m from the tunnel portal (with closed side walls) or as agreed with authorities having jurisdiction.

4.2.2 Marking

All nozzles shall have a clear and permanent marking text. Stamping or engraving is recommended. The marking shall identify the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.2.3 Maintenance

Nozzles not containing movable parts shall not be tested by means of an actual activation to prevent foreign material from entering into the piping downstream the section valve and into the nozzle. Instead random samples in the amount of 0.5% of the installed nozzles shall be yearly removed from the installation and inspected for their full function.

Nozzles containing movable parts shall be tested quarterly. Tests may be carried out by applying a different medium such as compressed air, but in this case such nozzles should be tested at least once a year with the actual fire fighting agent.

4.2.4 Material and temperature tolerances

Nozzles shall meet the requirements of the tunnel environment. Only high grade stainless steel shall be used for the nozzle body. The internal parts of nozzles should also be highly corrosion resistant.

Nozzles shall be capable of withstanding extreme temperatures before system activation. If the system is intended to be used in scenarios in which system activation is later than in the fire tests, suitable thermal tests and an assessment shall be carried out.

4.2.5 Filtration and protection caps

Nozzles shall have a strainer to prevent clogging due to particles carried by the agent. Strainers shall have mesh sizes no greater than 80% of the smallest water passage in the nozzle. For nozzles comprising movable parts, strainers should have mesh sizes no greater than 80% of the smallest tolerance in the nozzle to prevent blocking of the movable part.

Nozzles can have a means of applying protection caps to prevent foreign material from entering the nozzles. Such caps shall be releasable with no more than 50% of operating pressure in case of activation.

4.2.6 Installation sockets

Nozzles shall be installed in the piping with fittings or other methods that allow fast and easy replacement. Nozzles shall not be an integral part of the pipework. The nozzle fitting shall be made of the same material group as for the pipe it is installed on.

4.3 Section valves

Section valves serve as an interface between the main piping and the activated sections. Section valves are an important part of FFFS from the operation, reliability, maintenance and life cycle point of view.

4.3.1 Installation

The installation of section valves shall comply with the manufacturer's documented requirements. Section valves shall be installed under the soffit or on tunnel walls close to the soffit. It is essential that vehicles, even in the event of an accident, should not be able to damage section valves. Alternatively, section valves may be installed in emergency exits, service galleries or ventilation ducts or other areas protected from damage by vehicles. If valves are moved to other safe places in the tunnels, the pipe connections between the valves and sections shall be protected against damages by vehicles.

4.3.2 Marking

Section valves shall be marked with clear and permanent text. Stamping or engraving is recommended. The marking shall identify the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.3.3 Type and maintenance

Section valves shall be robust and durable for the tunnel environment. They shall be leakage free to avoid clogging of nozzles and keep the section pipes dry. Ball valves are recommended. Section valve design shall allow the valve to be opened and closed remotely by the control system. Section valves shall be provided with a manual override for opening and closing. The opening and closing instruction or rotation direction of the valve shall be clearly marked on the valve or directly beside it. The valve drive should be able to provide sufficient torque under all conditions; in particular, “break loose” effects must be taken into account. Means of monitoring that no leakage has occurred are recommended.

Valves shall be designed to prevent water hammer by having a limited operating speed (see Chapter *3.6.3 Water hammer effect*).

Section valves shall be equipped on the upstream side with a separate manual shut-off valve to allow the removal and replacement of each section valve without draining the main pipework or putting the whole system out of operation when changing the section valve. Each section valve shall have its own shut-off valve to avoid multiple sections being out of operation in the event of one shut-off valve being closed. The shut-off valve shall be lockable.

Special attention shall be given to the maintenance and testing of the section valves. Testing shall comply with the applicable regulations for such valves, but valve operation shall be tested at least quarterly. Depending on the requirements in the context of an RAMS analysis monthly tests can also be required. Means shall be provided to operate each section valve for test purposes without releasing water to the nozzles. Normally this is achieved by providing a second manually operated valve on the downstream side of the section valve.

Section valves shall be visually checked annually. Operating the manual shut-off valve shall be part of the annual check.

4.3.4 Material and temperature tolerances

Section valves and related shut-off valves shall be capable of withstanding the harsh tunnel environment and the type of fire fighting agent used. Only high grade stainless steel, to AISI316 or higher, shall be used for parts in contact with water or other fire fighting medium. The valve actuator shall have an appropriate IP class and be made of materials capable of withstanding the tunnel environment.

Section valves shall be capable of withstanding at least the minimum operating temperature range of the fire fighting agent. The valve actuator and other external parts of valves shall be capable of withstanding temperatures as measured inside its protective cabinet during full scale fire tests if the valve is installed within the protected area.

4.3.5 Valve protection cabinet

If installed within the protected area, section valves and the related shut-off valves shall be installed in protective cabinets. The valve cabinet shall have thermal protection against temperatures expected during a fire. The temperature inside the cabinet shall not exceed the maximum permissible temperature for the valves and the actuator. The valve cabinet should preferably be tested in full scale fire tests demonstrating that the temperature has been kept within acceptable limits. The valve protection cabinet shall also provide protection against dirt and water. If sub-zero temperatures are expected, the section valve and/or the protection cabinet shall have a means of heating.

If valves are installed outside the traffic tunnels in areas where there is no fire hazard, the valve protection cabinet will not need thermal insulation against high temperatures. It is still recommended that the valves be protected against dirt and misuse using a suitable cabinet.

The valve protection cabinet shall be lockable.

Only stainless steel shall be used as the external material of the valve protection cabinets if these are installed in the traffic tunnel. If valves are installed outside the traffic area, powder coated carbon steel may also be considered; the recommended colour is red as in other fire fighting equipment (RAL 3000).

4.3.6 Applicable standards

The following standards should be taken into account as general guidance in the design of FFFS section valves:

- DIN EN 1983
- EN 12845

4.4 Pumps

Apart from section valves, pumps are the only active mechanical parts in water-based systems.

4.4.1 Installation

Installation of pumps shall comply with the manufacturer’s documented requirements. Pumps shall be installed in a dedicated pump room or other designated area. Adequate ventilation and drainage shall be provided. The pump room shall be lockable to prevent access of unauthorised personnel.

4.4.2 Type and maintenance

Pumps used in FFFS are usually of the centrifugal or positive displacement types. Centrifugal pumps are typically used in low pressure and medium pressure systems, whereas positive displacement pumps are typically used in medium and high pressure systems.

The maintenance requirements for FFFS pumps are the same regardless of the type. The minimum maintenance shall be a monthly functional test with a short operation time and an annual main maintenance. The applicable regulations in individual countries shall be taken into account.

4.4.3 Pump configuration

Pump configurations for FFFS comprise one or more pumps. A dedicated pump controller for each pump room shall be provided for the operation of the pumps.

4.4.4 Marking

Pumps shall have a clear label identifying the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.4.5 Pump drive

A FFFS pump shall be driven by an electric motor or diesel engine. The pump shall be direct coupled to the drive and only one pump per drive shall be used.

The pump drive shall be capable of providing at least the maximum power required by the pump.

4.4.6 Pump capacity

FFFS shall be dimensioned to provide at least 110% of the nominal flow required for the most demanding protection area in the tunnel. This shall be calculated at the minimum nozzle pressure as type tested in full scale fire tests.

The required flow rate shall be provided by one or more pumps. It is recommended that the number of pumps in FFFS be limited by having a minimum pump capacity. The minimum pump capacity shall be 90 l/min per pump for positive displacement pumps and 750 l/min per pump for centrifugal pumps.

Pump flow rates shall be expressed as effective rates taking account of volumetric efficiency.

4.4.7 Pressure safety devices

Pumps capable of over-pressurising the system shall each be provided with a proper means of pressure relief to prevent excess pressure. The pressure in the FFFS shall in no case exceed the pressure rating of any component that may be in contact with the agent. Pressure relief devices, normally valves, shall be capable of discharging the total flow delivered by the pump or pumps at a pressure equal to the pressure rating.

Flow from the pressure relief devices shall not be directed back to the suction line of pumps, but to the tank or to a drain.

Each individual pump shall be equipped for safety reasons with an additional pressure relief valve (or valves) to protect against malfunction of overpressure.

4.4.8 Flow safety devices

Pumps having a flow rate dependent on pressure, e.g. centrifugal pumps, shall be equipped with a flow safety device. This ensures that the flow rate is limited in the event of an activation area close to the pump station with lower pressure loss in the piping. The main risks occurring with flow rates which are too high are related to the tank and drainage capacity. If both are dimensioned according to the maximum possible flow rate of the pumps, flow safety devices are not required.

A typical flow safety device is a flow control valve or an active pump control with a frequency converter.

4.4.9 Pump anchoring

Pumps or pump sets shall be properly anchored. The use of anti-vibration feet between pump frames and the floor is recommended.

4.4.10 Material and temperature tolerances

All parts of pumps which are in contact with the agent shall be of corrosion resistant material.

The operating temperature range shall be 4 to 54 °C for the pressure medium and 0 to 40 °C for the pump room.

$$Q_{water} = 110\% \cdot n_{nozzles} \cdot K_v \cdot \sqrt{p_{\min}}$$

Q_{water}	Required pumping capacity	[l/min]
$n_{nozzles}$	Number of activated nozzles	[pieces]
K_v	Kv-factor of nozzles	[l/min.bar-1)]
P_{min}	Minimum pressure at nozzles	[bar]

4.4.11 Filtration

The pump shall be protected against particles in the agent. This shall be achieved using a proper filter or strainer as described in Chapter *4.6.5 Booster pump.*

4.4.12 Pump controller

The pump control system of the FFFS should at least match the requirements regarding reliability and availability as defined for the control system of the emergency ventilation. It is recommended to implement all control systems for safety-critical systems in a tunnel with a SIL of 2

The pump system shall be equipped with a pump controller located in the same area. The installation shall comply with the manufacturer's documented requirements. The pump controller shall also control any other equipment forming part of the pump system such as water tank filling, jockey pumps, booster pumps and main filters.

Every pump shall be capable of being switched on/off manually for testing purposes. Manual operation shall be available only via overriding key switches. A local emergency start button shall be provided in case of failure of a remote start signal.

The pump controller shall have phase control and a corresponding alarm. This control will also indicate a reverse phase fault. The phase fault shall be indicated. The pump controller shall have voltmeters on the front panel.

All low voltage emitters and measuring devices, especially for pressure measurement, shall be online monitored to detect damage to any critical devices or cables.

A battery backup shall be included in the pump controller capable of providing 15 minutes of autonomy to buffer the PLC. In case of missing batteries or low voltage, the pump controller shall indicate a fault.

The pump controller shall provide red warning lights for the visual indication of all faults. Similarly when the system shows no faults, this shall be indicated with green lights. A test button for a lamp test shall be provided.

Pump controller programming shall include self-diagnosis and suitable service modes. The fault messages shall be divided into two main categories: A: Critical (immediate service needed, pump system out of operation); and B: Non-critical (service needed, pump system still operative).

The interface between the pump controller and the main control system depends on the network being used. In all cases full integration of operational messages as well as fault messages shall be transmitted to the higher level control system.

4.4.13 Applicable standards

The following standards should be taken into account as a general guidance in the FFFS pump systems.

- EN ISO 14847
- EN 12845
- EN 12259-12
- IEC 61508

4.5 Jockey pumps

Jockey pumps are used in most FFFS to keep the main pipes filled with the fire fighting agent and for detecting possible leakages.

4.5.1 Installation

The installation of jockey pumps shall comply with the manufacturer's documented requirements. Jockey pumps shall be installed in the pump room or other designated area. The place of installation shall be provided with suitable ventilation and drainage. The room shall be lockable to prevent the access of unauthorised personnel.

Jockey pumps shall be installed with an isolating check valve to prevent pressure reaching the jockey pump in the event of system activation.

Jockey pumps shall be connected either to a separate water supply from the town main or to the water tank.

4.5.2 Type and maintenance

Jockey pumps are usually of the positive displacement type. Also centrifugal pumps are used Pumps shall start automatically upon a pressure drop in the system and shall stop automatically when pressure in the system returns to the set value. The pressure measurement system shall be redundant. In the event of overpressure, the jockey pump system shall be protected by suitable elements to avoid any safety risk and to comply with relevant installation guidelines/regulations.

A test valve shall be provided in the jockey pump piping. The maintenance of jockey pumps should follow the same sequence as for the main pumps.

4.5.3 Marking

Pumps shall have a clear label identifying the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.5.4 Jockey pump drive

The jockey pump shall be driven by an electric motor. Air drives shall not be used.

The pump drive shall be capable of providing at least the maximum power required by the system.

4.5.5 Material and temperature tolerances

All parts of jockey pumps being in contact with the agent shall be manufactured from corrosion resistant material. The use of stainless steel is recommended.

The operating temperature range of pumps shall be 4 to 54 °C for the pressure medium and 0 to 40 °C for the pump room.

4.5.6 Filtration

The jockey pump shall be protected against particles in the agent. The mesh size shall be no more than 80% of the smallest water passage in the system or as required by the manufacturer. The use of self-flushing filters is recommended.

4.5.7 Applicable standards

The following standards should be taken into account as a general guidance in the design of fixed fire fighting pumps.

- EN ISO 14847
- EN 12845
- EN 12259-12

4.6 Water tanks (reservoirs)

The water tank shall be suitable for providing water for all simultaneously activated sections (typically two or three) with the required flow rate for the defined minimum period of operation.

The water tank may be combined with water storage facilities for fire brigade purposes. The refilling of water tanks by the fire brigade shall be considered.

The use of break tanks is not recommended.

4.6.1 Installation

The installation shall comply with the manufacturer's documented requirements. The tank design shall take account of relevant standards.

Tanks should be installed close to the FFFS pumps, typically less than 30 meters away.

They shall be provided with a vent to atmosphere to avoid over or under-pressure. This venting shall be protected by a breather filter to avoid access of particles into the tanks.

Tanks shall be locked in order to avoid misuse or access of unauthorised personnel.

Tanks shall have a lockable manhole for maintenance. They shall be equipped with a water level sensor configured to give an alarm in the event of low level. A lockable drain valve shall be placed in the outlet of the tank for maintenance purposes.

The tank shall be labelled with its volume.

4.6.2 Water tank volume

The water tank volume shall be defined as part of the overall safety analysis for every tunnel, based on the maximum response time of fire services (time to commence fire fighting). The tank volume shall be determined in conjunction with the authorities having jurisdiction.

The minimum volume of the water tank shall be equal to the total pumping rate for a minimum of 30 minutes of operation for tunnels less than 500m at the maximum pump capacity, or at the set value of the flow safety device as described in Chapter *4.4.8 Pressure safety devices*. Therefore a minimum of 60 minutes shall be used for tunnels longer than 500 m.

In any case the water supply shall last for a period of time that is double the time required for the emergency services to reach the fire (taking into account worst case conditions such as traffic congestion). This minimum time of operation may be changed by the authorities having jurisdiction.

4.6.3 Material

The tank material may be coated carbon steel, coated concrete, stainless steel or plastic/composites. The tank material shall not produce any foreign material. Both the tank material and the degree of cleanliness of the water shall be taken into account when determining the main filter capacity.

4.6.4 Booster pump

A booster pump shall be installed between the water tank and the FFFS pumps. The installation shall comply with the manufacturer's documented requirements.

The purpose of the booster pump is to pump the fire fighting agent through the main filter and provide the pump system with positive suction pressure. Booster pumps are typically low pressure centrifugal pumps. The booster pump shall be installed with 100% redundancy or shall be equipped with an automatic by-pass in case of failure of the booster pump.

Booster pumps shall be dimensioned depending on the hydraulic design between the tank and the pumps.

Booster pumps shall have clear permanent marking. Stamping or engraving is recommended. The marking shall identify the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.6.5 Main filter

The main filter shall be installed between the booster pump and the main pumps. The installation shall comply with the manufacturer's documented requirements.

The main filter shall be made of stainless steel. The filter shall have sufficient capacity for the purpose and for the expected water filtration level. The filtration mesh size shall be no greater than 80% of the smallest water passage in the system or as required by the manufacturer. However, limits of 300 µm for deluge systems and 150 µm for water mist systems are common values.

The main filter shall have an electric device, e.g. a pressure difference sensor, to provide a warning if the filter element is becoming blocked. In addition, a visual indication in the filter body should show the same.

The main filter shall be clearly marked with the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

4.6.6 Temperature tolerance

The water tank shall be designed to avoid freezing of the fire fighting agent. If a booster pump or main filter is also installed in the area and temperatures below 0℃ are expected, a means of heating shall be provided.

4.6.7 Maintenance

The water tank should be visually checked monthly.

The water quality should be checked monthly. The water tank should be drained, cleaned and checked every 3 years.

Booster pumps and the main filter shall be tested with the same frequency as the main pump system.

4.6.8 Applicable standards

The following standards should be taken into account as a general guidance.

- EN ISO 14847
- EN 12845
- EN 12259-12

4.7 Pipework and fittings

The pipework consists of main pipes and section pipes. Main pipes are normally water-filled during standby and deliver fire fighting agent to the section valves. The section valves are downstream connected to the section pipes and nozzles, which are empty (dry) during standby. In case of activation the section valves deliver fire fighting agent to the nozzles installed in the respective section

Connections include all connecting components such as flanges, fittings and other piping components.

All pipework shall be fitted in safe areas in the tunnel cross-section (see Chapter 3.4.2 Location of components).

Typical terms used for different parts of FFFS are as follows: branch pipes, manifolds and main pipes (branch and manifold pipes together are known as section pipes). These all are shown in the explanatory figure 3.

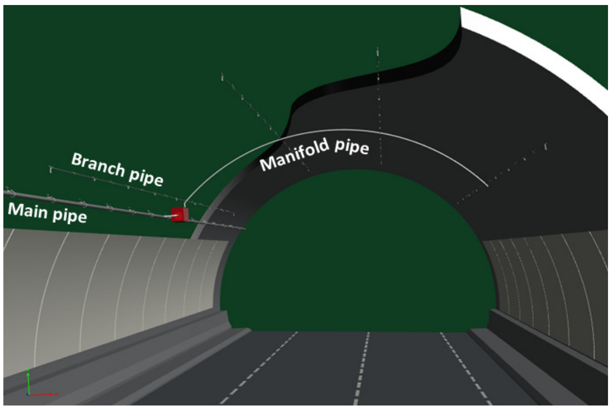

Figure 3: Schematic pipe network in the tunnel

4.7.1 Pipe and fitting material

The pipe material shall be suitable for the harsh tunnel environment and for the fire fighting agent. Only high grade stainless steel to AISI316 or higher shall be used in all parts of pipework in contact with the fire fighting agent.

Pipes shall be delivered with material certificates.

4.7.2 Pressure rating

The pipework shall be able to withstand at least 1.5 times the design pressure (calculation temperature 54 °C, or as otherwise defined by the authorities having jurisdiction). Where a pressure reducing device is used in the system, the pressure rating of the pipework shall be determined taking into account the maximum foreseeable pressure in the system.

All pipework shall be marked along its length by the manufacturer in such a way as to identify the type and size of pipe. Pipe marking shall not be painted, concealed or removed prior to approval from the authorities having jurisdiction.

4.7.3 Straight pipes and bending

Pipes may be either seamless or welded type. Seamless pipes shall conform to EN 10216 and welded pipes to EN 10312, as applicable.

Pipes shall be manufactured in such a way as to allow bending; otherwise bending shall not be used. The pipework must be type "m" or higher for seamless pipe (EN 10216 Part 5) or type "W1, W1R, W2, W2R" for welded pipes (EN 10217 Part 7).

4.7.4 Pipe joints and fittings

To provide a long life time, robust connections and to keep maintenance costs low, welding is recommended as the main pipe connecting method including welded joints. Welded connections do not need any service. Welding shall be performed in accordance with the manufacturer's documented requirements. Welders shall be certified in accordance with EN 287 Part 1 with applicable parts. Automatic orbital welding machines should be used where suitable. Orbital welders shall be certified in accordance to EN 1418 with applicable parts.

Use of threaded joints is permissible within certain limitations and precautions. Threaded joints and sealing methods shall apply long design lifetime expectations and be capable of withstanding vibration and thermal effects, see Chapter *3.4.3. Thermal effects and temperature rating*. The pipe wall thickness for threaded connections shall be no less than 3 mm in pipes on discharge side of FFFS pumps. All threaded connections shall be visually checked annually for possible leakage and tightness.

Compression or press-on fittings may be used, with certain limitations and precautions. In particular, the requirements on tolerances of the outside diameter of the pipe shall be complied with. Compression or press-on fittings must comply with tolerance classes D3 or D4 or higher in accordance with EN 1127. In all cases the required tolerance shall be in accordance with the manufacturer's documented requirement. Such joints shall apply long design lifetime expectations and be capable of withstanding vibration and thermal effects, , see Chapter *3.4.3. Thermal effects and temperature rating*. All compressed or press-on joints shall be visually checked annually.

Fittings shall be in accordance with the standards specified by the pipe manufacturer and the manufacturer's documented requirements. Fitting materials shall guarantee a corrosion resistance at least equivalent to the corrosion resistance of the pipework, which applies to both internal and external parts. All types of fittings are acceptable providing they comply with the design characteristics of the pipe and with the pressure rating. All fittings shall apply long design lifetime expectations and be capable of withstanding vibration and thermal effects. All fittings shall be visually checked annually for possible leakage and tightness.

4.7.5 Pipe supports

Pipe supports shall be in accordance with the manufacturer's documented requirement and ISO 6182-11 with respective parts. The manufacturer shall provide evidence that the following basic requirements are met:

- load
- vibration
- water hammer
- heat resistance

Pipe supports shall be suitable for the environmental conditions, for the expected temperature, including the stresses induced in the pipework by temperature variations, and be able to withstand the anticipated dynamic and static forces. Especially in rail tunnels, air pressure variation causing aerodynamic load shall be considered when designing the support system. The minimum safety factor of 5 in accordance with EN 12845 shall be applied in static load calculations.

Material of pipe supports shall be suitable for the purpose and comply with applicable national regulations. Stainless steel is recommended. If another material is used, galvanic corrosion shall be prevented by using proper insulation material.

Anchors form an integral part of pipe supports and shall meet similar requirements. The anchor material shall be determined in conjunction with the authorities having jurisdiction, but stainless steel is recommended.

4.7.6 Drain and vent valves

Drain and vent valves shall be installed in accordance with the manufacturer's documented requirements. Valves shall be leak free and have the same material, pressure and temperature tolerance requirements as other parts of the piping system. The use of ball valves is recommended. Valves shall be lockable where accessible by unauthorised people.

Drain and vent valves shall be marked with clear permanent text to identify the following information:

- Manufacturer's name
- Part number
- Manufacturing batch or tracking number
- Year of manufacturer

All vent and drain valves shall be operated (opened and closed) at least once a year preventing sticking.

4.7.7 Thermal requirements

All pipework and related components shall be capable of withstanding the entire temperature range expected (see Chapter *3.4.3 for more details*). In the case of a freezing risk, use of antifreeze or trace heating shall be considered. Alternatively, the main pipe may be dry and air filled, but only provided if it can be filled within time required for operation, see Chapter *3.8.3. Time to operation.*

If an anti-freeze additive is used, it shall be proven to the satisfaction of the authorities having jurisdiction that such additive has no adverse effect on fires and does not constitute a health hazard for tunnel users.

If trace heating is used, it shall be thermostatically controlled. One thermostat may control a section of tunnel up to 200 m long. Trace heating shall be insulated and covered with a stainless steel sheet for mechanical protection of the insulation. The manufacturer shall provide the authorities having jurisdiction with thermal calculations demonstrating the suitability of the heating system.

5. Installation

5.1 Safety aspects

Safety during installation is the responsibility of the contractor. National regulations as well as site rules shall be followed. This shall cover as a minimum the aspects described in this chapter.

5.2 Off-site work

5.2.1 Prefabrication

Typical prefabricated parts of FFFS include:

- Components: Nozzles, section valves, section valve cabinets, supports, anchors
- Pump station: Pump units/sets, booster pump units, jockey pump units, electric cabinets
- Pipe modules: Section pipe kits, main pipe modules

5.2.2 Quality control

The quality control in off-site works shall be in accordance with the manufacturer's documented quality system and specifications of the client. The contractor shall implement a quality control file for the reference of the client to identify project related quality personnel for off-site works.

5.2.3 Factory testing

Factory testing is an important part of the test procedures which are detailed below in principle for various components:

Section valves:

- Full operational test
- Pressure test
- Leakage test
- Testing of possible pilot valve or actuator with limit switches or other control system

Pump sets:

- Full operational test at the design flow rate
- Operational test at design pressure
- Minimum 15 minute test run

Jockey pumps:

- Full operational test

It is recommended that factory tests be carried out under the supervision of the authorities having jurisdiction. The factory test protocol shall be delivered to the involved parties prior to testing. After the factory tests, a test report shall be provided. The test report shall identify the specific components tested and the test measurements.

5.2.4 Transport

Transport shall comply with good practice. Equipment and components shall be properly protected during transport and storage. This applies especially to pipes and other hydraulic parts which shall be plugged in order to prevent the access of foreign material.

5.3 On-site work

Installation shall be performed in accordance with the manufacturer's documented requirements and the approved design drawings.

All work shall be carried out as part of a documented quality management system, which should at least meet the requirements of ISO 9001.

5.4 Commissioning

Commissioning of FFFS includes both final testing and proof of system operation. Commissioning may be divided into various stages, also referred to as partial acceptance testing. Final overall testing with all parts involved is often referred to as functional acceptance testing. This includes testing of interfaces with all other system parts.

5.4.1 Mechanical and hydraulic commissioning

Mechanical commissioning includes the testing of the pump station, section valves, nozzles and related pipework.

Before actual testing of the system, it shall be checked that all mechanical and hydraulic components are shown on the drawings and are installed in the right places in the system.

The first part of the mechanical and hydraulic commissioning is related to flushing and pressure tests as described in Chapter *3.6.5.*

The second part of commissioning testing is related to the operation of the system. The FFFS shall be activated at the least favourable hydraulic location of the system to prove the hydraulic design by measuring the operating pressure at or close to the most remote nozzle. The pressure shall be no less than shown in the hydraulic calculations. The test shall be carried out with the fire fighting agent and, if foreseen, additives to simulate a real operation of the system.

The pump station and section valve(s) or any other control devices may be activated automatically in such a test. The test should be continued for at least 30 minutes, during which time possible vibration, noises, movements, leakage or other abnormal effects in the piping should be documented.

All tests shall be performed according to a predefined protocol to be submitted authorities having jurisdiction and other involved parties prior to testing.

5.4.2 Commissioning of electrical and control equipment

Electric commissioning includes testing of the control equipment and software.

Before the actual test, all electric equipment, components and cabling, shall be checked for compliance with the design drawings and the documentation.

Operational tests shall as a minimum include the pump station(s) and all section valves. At the pump station a full operational test with a simulated activation signal shall be carried out. All other possible scenarios and redundant modes such as failure of pumps, pressure sensors, cable breakage, etc. shall be tested.

All section valves or other remotely controlled valves shall be tested for safe operation.

All tests shall be performed according to a predefined protocol to be submitted to the authorities having jurisdiction and other involved parties prior to testing.

5.4.3 Functional commissioning

Functional commissioning includes the main operational test with a simulation of one or more fire scenarios (no real fire is used.). The FFFS and the entire safety concept shall be tested as a whole. It shall be ensured that all system parts including detection, control and communication systems, water supply and other related systems are fully operational.

Functional commissioning may also be part of full emergency training.

All tests shall be performed according to a predefined protocol to be submitted to the authorities having jurisdiction and other involved parties prior to testing.

5.4.4 Emergency training

Emergency training is a recommended exercise in which all the tunnel safety systems, including FFFS, will be tested in conjunction with the emergency services in a simulated fire incident. Training the emergency services to operate with the FFFS is an important part of testing.

5.4.5 Handover documentation

Handover documentation shall include as a minimum all design and installation drawings in as-built status, and maintenance documents with spare part numbers.

5.4.6 Basic maintenance training

Basic maintenance training shall enable the maintenance personnel to understand the system operation in detail. Suitable personnel shall be trained to carry out regular maintenance works, to diagnose basic failures exchange standard parts, replace consumables and to organize the intervention of an expert company if required.

Training may be organised both on site and/or in the contractor's premises for special equipment.

5.5 Installed System certification

FFFS shall be certified by an authority having jurisdiction to comply with the design parameters derived from fire testing, manufacturers' documented requirements and the project specification. Conformity with any relevant requirements of the country of installation shall be stated.

6. Activation and operation

6.1 General

FFFS may be activated and operated manually or automatically depending on the availability of trained personnel, the risks expected, the type of FFFS, the control systems used and applicable legislation. The main principles are explained at the thematic level in this chapter.

6.2 Activation principles

6.2.1 Manual activation

A pre-condition for manual operation is a 24/7 manned tunnel control room. Manually operated FFFS are activated and controlled by the operator or the fire services. Manual operation shall only be acceptable if the operator is provided by the control system with sufficient information about the fire incident and is trained sufficiently to take decisions based on this. The operator shall be in charge until the fire services have arrived in the tunnel. Manual operation of the FFFS includes de-activation of sections and the following activation of other sections as the fire develops.

It is recommended that a manually operated system be equipped additionally with automatic means of activation as a backup. The automatic activation shall take place at a temperature level which is set higher than in systems designed for automatic operation alone. In this case, manual activation would be expected; should this not happen, the system shall still be activated at a pre-set temperature.

6.2.2 Automatic activation

Automatic FFFS are activated and operated based on signals received from the detection, localisation and control systems. These signals shall allow the control system of the FFFS to automatically adjust the sections to be activated and closed. Automatic operation shall continue until the fire services reach the tunnel and take over control of the FFFS. In all cases an automatic FFFS shall be equipped with means for manual operation as a backup.

6.3 Operation and deactivation

6.3.1 Number of activated sections

At least two sections of the FFFS shall be activated in case of fire. The recommended minimum section length is 20 metres. If three sections are

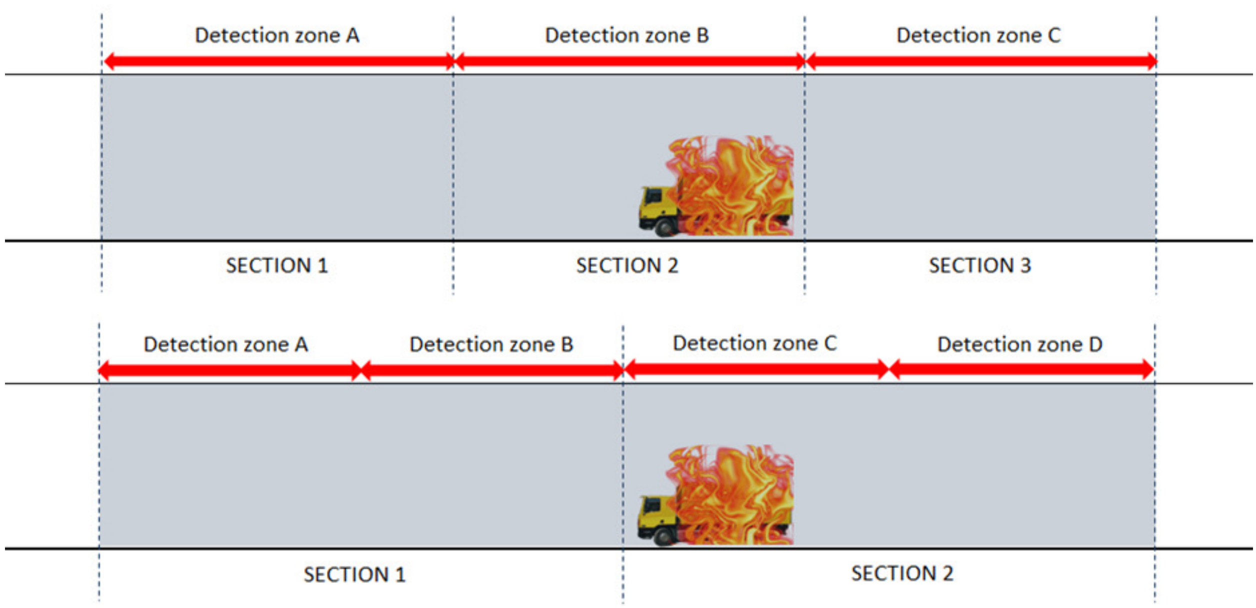

Figure 4: Localisation and activation of the designated area

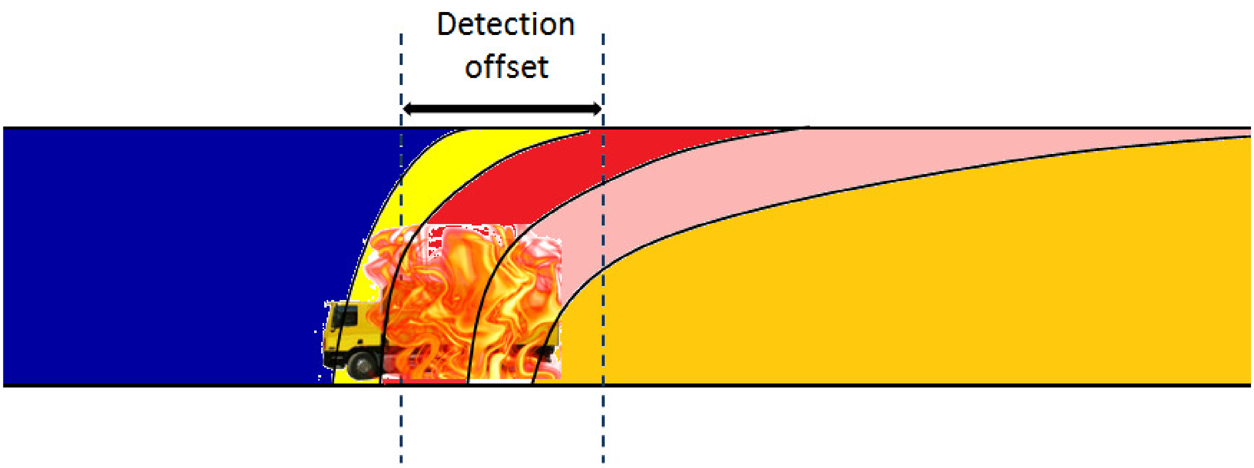

Figure 5: Schematic of the detection offset

activated, the section length can be shorter provided that the total activation length is no less than 50 m. In all cases the total activation length shall be supported by full scale fire test results and the risk analysis taking into account the precision of the detection / localisation system and other aspects.

6.3.2 Activated sections and detection

The number of activated sections shall be in line with the minimum accuracy of the detection / localisation system. If three sections are normally activated the minimum localisation zone length shall be the same as the section length of the FFFS. Two adjacent sections on both sides of the section in which the fire has been detected shall be activated. .

If only two sections are activated, the minimum accuracy of the localisation system shall be half the length of a section. More precise localisation is recommended to provide better information concerning which of the adjacent sections should be activated and how the fire develops.

If linear heat detection / localisation is used, it is important that the offset distance, caused by the ventilation moving the detection point downstream from the actual fire, be taken into account when programming the control system. It is recommended that FFFS be type tested at full scale in conjunction with the type of detection / localisation technology to be used.

6.3.3 Activation time

The activation time of the FFFS shall be determined in the risk analysis for every individual tunnel. The system shall be capable of a minimum activation time of 30 minutes, although longer activation times are normally required, *see Chapter 4.6.2* Water tank volume*)*. The design activation time shall be derived from the detailed risk analysis that takes account for example of the response time of the fire services.

6.3.4 Deactivation

FFFS shall be deactivated only by fire services or authorised personnel.

6.4 Fire incident operating protocol

For the case of a fire incident, a dedicated operating protocol for all parties involved in the emergency shall be prepared. The protocol shall be worked out jointly with all parties involved in the rescue and emergency activities. It shall comply with national legislation and also be approved by the authorities having jurisdiction. The operation protocol predefines responsibilities as well as tasks and actions to be carried out by the parties involved.

7. Inspection and maintenance

7.1 General

A strict and regular maintenance programme shall be followed to ensure the reliable operation of the fixed fire fighting system. Maintenance shall be carried out in accordance with the maintenance manual provided by the manufacturer. Only personnel authorised and trained by the manufacturer shall be allowed to carry out maintenance.

The operator's inspection programme shall ensure faults are detected at an early stage in order to allow rectification before the system is required to operate. The manufacturer shall provide the tunnel operator with monitoring software to collect the history of service and maintenance activities, running times of the pump system, failure reports etc. The software shall include instructions on actions to be taken in case of faults and malfunctions.

7.2 Regular maintenance

Maintenance operations are normally subdivided into three different operational levels, depending on the frequency.

7.2.1 Annual main maintenance

The annual main maintenance is the highest level maintenance activity and shall include major operational testing of the system. This shall include testing of the FFFS in conjunction with other safety measures. As a minimum the following tasks shall be carried out:

- Pump stations:
  - Water quality check
  - Filter cleaning
  - Oil change of pumps/diesel engines
  - Battery checks
  - Software tests
- Section valves and protection boxes:
  - Visual check
  - Cleaning
- Nozzles:
  - Visual check
  - Random detailed check of individual nozzles
- Control systems:
  - Interface tests
  - Software tests

7.2.2 Monthly basic maintenance

Monthly maintenance is the main operational level of maintenance to ensure that all system parts are functional. The testing shall be performed for all active parts of the system. As a minimum the following actions shall be included:

- Pump stations:
  - Filter check
  - Pump tests
- Section valves and protection boxes:
  - Operating test of section valves
- Nozzles (quarterly):
  - Only if these are active components is an operational test required.

7.2.3 Weekly basic maintenance

Weekly maintenance is not normally required unless the manufacturer requires this. A visual check of the pump system is recommended.

7.3 Spare parts

The most common spare parts shall be provided on site as part of the FFFS supply. If the FFFS is designed for predefined target availability, spare parts shall be defined in RAMS studies to provide fast recovery times to meet such target.

8. Disclaimer

This engineering guidance document does not constitute a legally mandatory requirement. It reflects results of the research project SOLIT², as well as findings from other projects, know-how and experience of experts in the field. Other research work currently being carried out or planned to be carried out may change the technical recommendations included in this document.

All information, guidance, recommendations and data have been generated and compiled with reasonable care. It is the reader's sole responsibility to verify in each case whether the content of this document is suitable for and may be used in connection with a specific project. The reader is deemed to be an expert in the field of fire protection in tunnels.

9. Sources

9.1 Figures

Unless otherwise stated, the rights for figures in this document belong to the partners of the SOLIT² consortium. For all other figures a link to the full source is given. The usage is based on the German UrhG §51 Nr.1.

9.2 Further Literature

The below listed sources can be requested for scientific work through the project coordinator, provided that they are publicly accessible and not subject to a confidentiality agreement.

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